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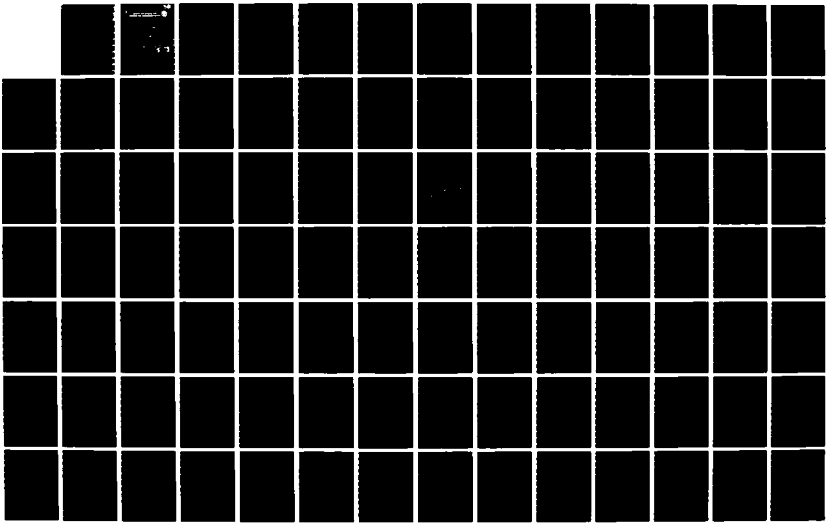

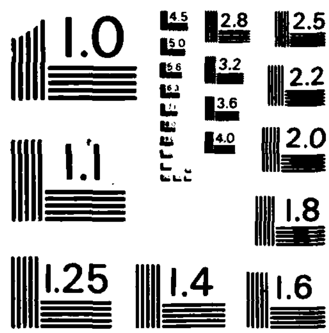

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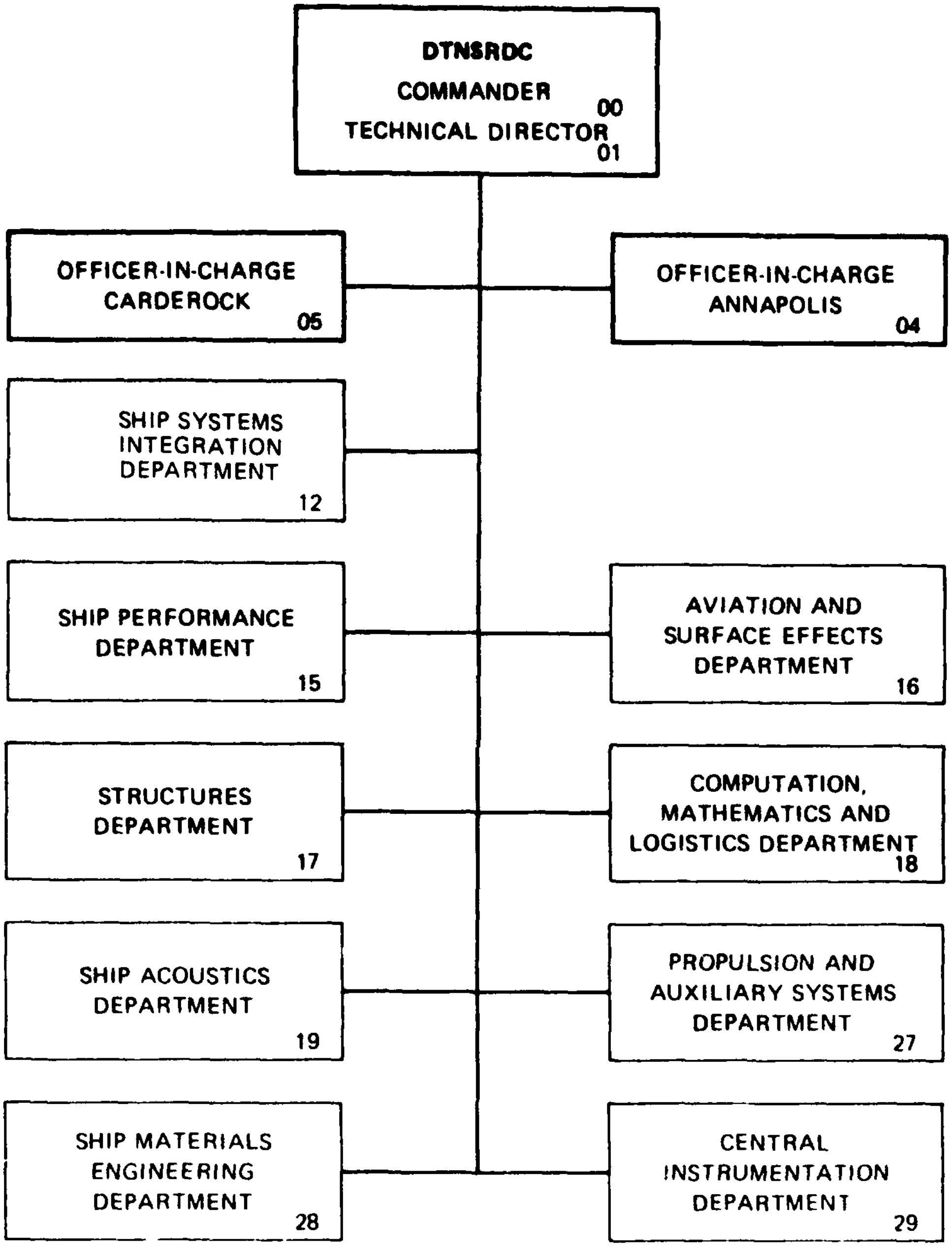

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Full scale maneuvering trials were conducted on a river tow/barge flotilla on Lake Pontchartrain in New Orleans, Louisiana, in the summer of 1985. The trials were conducted in order to obtain tow maneuvering performance data for comparison with tow tank and simulator generated data. Calibration runs, turning maneuvers, horizontal overshoot maneuvers, acceleration and deceleration maneuvers, and lateral motion maneuvers were performed for three different tow/barge configurations. Water depth averaged 17 feet ±2 feet (4.6 meters ± 0.6 meters) during the trials and the water depth to draft ratio was a nominal 1.9. Measurements obtained during the trials included steering and flanking rudder angle, port and starboard shaft speed, tow heading, tow turning rate, relative wind velocity, and tow position.

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ABSTRACT

Full scale maneuvering trials were conducted on a river tow/barge flotilla on Lake Pontchartrain in New Orleans, Louisiana, in the summer of 1985. The trials were conducted in order to obtain tow maneuvering performance data for comparison with tow tank and simulator generated data. Calibration runs, turning maneuvers, horizontal overshoot maneuvers, acceleration and deceleration maneuvers, and lateral motion maneuvers were performed for three different tow/barge configurations. Water depth averaged 17 feet ± 2 feet (4.6 meters ± 0.6 meters) during the trials and the water depth to draft ratio was a nominal 1.9. Measurements obtained during the trials included steering and flanking rudder angle, port and starboard shaft speed, tow heading, tow turning rate, relative wind velocity, and tow position.

ADMINISTRATIVE INFORMATION

The maneuvering trials reported herein were authorized by, and conducted in accordance with, U. S. Coast Guard Military Interdepartmental Purchase Request Number DTCG23-85-F-20026. The work was accomplished under David W. Taylor Naval Ship Research and Development Center Work Unit 1523-431.

INTRODUCTION

An interest in improving the cost effectiveness of vessels operating on the open sea or in any waterway environment has resulted in the construction of larger and larger commercial vessels. The increasing size and displacement of these vessels have also been accompanied by a need for better trained operators as the shiphandling complexity generally increases with size, particularly when operating in shallow water.

In conjunction with such changes in the shipping industry, special facilities have been developed for the purpose of providing operator training through real-time shiphandling simulators. Shiphandling simulators utilize maneuvering mathematical models through the use of Newton's equations of motion.[1*] Physical rudder movements and sizes, wind and current forces, and water depth must be accurately known to properly program shiphandling simulators.

*A complete list of references is on page 187.

Full scale trial data must be obtained periodically in order to ensure the accuracy with which a given configuration is simulated. The need for such empirical data provided the impetus for trials on various tow configurations owned by the U. S. Army Corps of Engineers. Extensive maneuvering trials were therefore conducted during the period 29 July 1985 through 3 August 1985 on Lake Pontchartrain in New Orleans, Louisiana.

This report is intended to provide a description of the methods used to accomplish the trials, and to present an overview of the results obtained. An in-depth analysis of the trial results, including the use of system identification techniques to determine maneuvering hydrodynamic coefficients is to be accomplished at a later date.

GENERAL

Preliminary planning for maneuvering trials on M/V BENYAURD began during conferences in February and March of 1985 at the U. S. Coast Guard Headquarters in Washington, D. C. As a result of these meetings it was determined that David Taylor Naval Ship Research and Development Center (DTNSRDC), Code 1523, would be responsible for the following items:

1. Preparation of a trial agenda
2. Selection and installation of trial instrumentation
3. Conduct of the trials
4. Data analysis and report preparation
5. Preparation of a nine track magnetic tape to be used for future data analysis.

It was also determined that DTNSRDC, Code 1561, would provide technical advice concerning items (1) and (3). Thus the trials were to be a joint effort among the Coast Guard, the Army Corps of Engineers, and DTNSRDC.

TOWBOAT SELECTION

The M/V BENYAURD, a twin screw river towboat, was selected as the prime mover for the subject maneuvering trials. BENYAURD is used primarily on the Mississippi River and is owned and operated by the U. S. Army Corps of

Engineers and is based at the Mat Sinking Facility, Vicksburg, Mississippi. BENYAURD was built by Jeffboat, Inc. of Jeffersonville, Indiana and was launched 3 February 1979.

TRIAL PREPARATION

SITE SELECTION

Lake Pontchartrain in New Orleans, Louisiana, was considered to be a suitable site for the subject trials. Lake Pontchartrain could be reached in approximately two days by the M/V BENYAURD and the barges needed for the trials. Charts of the lake indicated that adequate maneuvering areas existed, and that the water depth was reasonably constant, varying between 13 feet (3.9 meters) and 16 feet (4.9 meters). In order to confirm the suitability of Lake Pontchartrain for the subject trials, a site survey was conducted by personnel from the U. S. Army Corps of Engineers and DTNSRDC.

An area in the southeast corner of Lake Pontchartrain was tentatively identified as a suitable trial site. On 21 May an abbreviated bottom survey was conducted utilizing a fathometer with a strip chart recorder and a Loran C navigation system. Although the survey was shortened due to severe thunderstorms, the survey indicated a relatively flat bottom; water depths of 15 feet (4.6 meters) to 16 feet (4.9 meters) were measured. On 15 July 1985, DTNSRDC was notified by Coast Guard Headquarters that the proposed trial site was unacceptable due to commercial traffic. A compromise was eventually reached and the trial site was moved to the south approximately two miles.

A chart of the resulting test site is shown in Appendix A. A detailed description of the location of reference stations (transponders) used to obtain towboat/barge position data can also be found in Appendix A. Personnel from the New Orleans Coast Guard District deployed marker buoys at the corners of the test site to provide an additional frame of reference during the trials. Coast Guard personnel also patrolled the area during the trials in order to keep the area as free as possible from local traffic. As a result of the above steps, very few delays were experienced due to local traffic.

INSTRUMENTATION

The majority of the required trial instrumentation was installed by personnel from the Full Scale Trials Branch of DTNSRDC during the period 22 through 26 July 1985. Installation occurred at the U. S. Army Corps of Engineers Mat Sinking Facility in Vicksburg, Mississippi. During this time the fifteen barges to be used in the tow were loaded with water or cement mats in order to achieve the proper displacement.

As discussed during the pre-trial conferences, the towboat and barges were instrumented such that the measurements listed below could be recorded automatically every four seconds.

Time in seconds
Steering Rudder Angle in degrees
Flanking Rudder Angle in degrees
Port Shaft revolutions per minute
Starboard Shaft revolutions per minute
Towboat Heading in degrees
Turning Rate in degrees per second
Wind Speed in knots
Wind Direction in degrees
Tow Bow Position in yards (X-Y coordinate system)
Tow Stern Position in yards (X-Y coordinate system)
Forward and Lateral Speed through the water

Tracking antennas were installed on both the bow and the stern of the tow configuration to insure that the tow heading could be determined even if the output of a heading gyro was not available. (During the planning stage it was not certain that a heading gyro would be available for the trials.) Details of the tracking techniques are presented in Appendices A and B.

Water depth was to be recorded separately via a fathometer and a strip chart recorder as the ship's fathometer was not equipped with an output signal suitable for easy interface with the trial instrumentation. In view of the time and costs associated with the interface effort, it was decided to record this signal separately. However, due to a failure in the depth recorder, depth was not obtained.

There were no significant difficulties or delays experienced during the installation period. The timely completion of the installation was accomplished through the excellent cooperation of the M/V BENYAURD personnel.

A detailed description of the installation and calibration procedures is provided in Appendix B. (Dual axis electromagnetic water current meters were installed after the tow was configured at the test site. See Appendix B.)

TRIAL AGENDA

The trial agenda was developed with the intention of obtaining the maximum amount of information per unit time in support of the primary objective, the collection of maneuvering performance data for comparison with existing tow tank and simulator generated data. Properly processed full scale trial data can be used to resolve questions regarding scale effects and model structure.

Comparison with simulator data requires the development of a set of differential equations which represent the tow's motion response to external inputs such as rudder angle and propeller speed commands or water currents.[2] Coefficients required for the definitive equations can be determined from full scale motion data via the system identification statistical data processing technique.

Determination of the necessary coefficients requires that certain types of maneuvers be performed in order to fully define the dynamic characteristics of a given tow. Furthermore, each maneuver should produce ship motions which relate strongly with only a small subset of the total set of hydrodynamic coefficients. Thus by judicious selection of trial runs, various subsets of coefficients can be isolated from one another in a sequential manner to facilitate the development of a complete hydrodynamic model by system identification data processing.

Table 1 lists the significance of the relevant nonlinear coefficients to six different types of maneuvers. Maneuver types listed in Table 1 are small amplitude zig-zag, large amplitude zig-zag, small amplitude turn, large amplitude turn, accelerated turn, and translational acceleration or crash stop. "Amplitude" refers to the magnitude of the rudder angle and is considered to be small if less than 12 degrees. The significance of the numerical values is as follows:[3]

0 means no significance,

1 means very small significance,

2 means moderate significance, and

3 means very strong significance.

The resulting trial agenda was developed from basic maneuver types recommended by Reference 2. The maneuvers include zig-zags, accelerating and decelerating zig-zags, coasting zig-zags, accelerating turns, acceleration runs, and crash stops. Several steady turning circles were also included in the trial agenda in order to determine the magnitude and direction of water currents in the test area, and to determine steady turning characteristics such as tactical diameter. The order of execution of the various maneuvers was selected to make best use of the test area available and thus minimize the total test time. See Appendix C for a chronological list of the runs conducted.

TOWBOAT/TOW CHARACTERISTICS AND TRIAL CONDITIONS

M/V BENYAURD was named in honor of Lieutenant Colonel William Henry Harrison Benyaurd. Lt. Col. Benyaurd was awarded the Congressional Medal of Honor for conspicuous gallantry in action on 1 April 1865 at Five Forks, Virginia, during the Civil War.

The M/V BENYAURD, a twin screw steel river towboat, is 170 feet (51.8 meters) long and has a breadth of 40 feet (12.1 meters). The registered tonnage is 1,027 tons gross (1,043 metric tons) and 682 tons net (693 metric tons). Table 2 lists the hull and machinery data for the BENYAURD.

Three separate tow configurations were tested during the week of trials on Lake Pontchartrain. Rake end barges with a length of 195 feet (59.4 meters) and a breadth of 35 feet (10.7 meters) were used for each of the three tow configurations. The first or baseline tow configuration consisted of 15 barges, arranged three abreast and five rows deep. Figure 1 shows the baseline configuration along with the location of the test equipment on the tow/barge. The majority of the maneuvers were conducted in the baseline configuration.

Two other configurations were tested using different arrangements of six barges. The first six-barge tow was configured using barges two abreast (wide)

and three rows deep (long). This configuration was the longer of the 2 six-barge configurations and is referred to as the "long tow" or configuration L. Figure 2 shows the long tow configuration along with the arrangement of test equipment on the tow. The "wide tow" or configuration W, consisted of barges three abreast and two rows deep. This wide configuration along with the location of test equipment can be seen in Figure 3.

Each individual barge, shown in Figures 1 through 3, has been numbered to identify the barges used in each arrangement. The barges were maintained at a nominal 9 foot (2.74 meter) draft. On the third day of testing the outside barges were taking on water from high waves and were pumped out in order to maintain proper drafts. Table 3 lists the draft readings taken on each barge for each configuration.

The trial conditions for the week of testing were considered to be very good with the exception of some high winds and lake chop of approximately 2 to 3 feet (approximately 1 meter) encountered during the morning of 2 August 1985. The winds and seas delayed the trials for approximately three hours but successful testing was conducted for the remainder of the day. Local afternoon thunderstorms encountered later in the week produced drastic changes in wind direction along with some increase in wind strength. The approach headings on the runs were changed as necessary to help minimize the effects of crosswinds. All wind data (relative speed and direction) are included on the data tape provided to the Coast Guard.

The water depth throughout the test area was observed to be 17 feet ±2 feet (5.2 meters ± 0.6 meters) and the bottom appeared smooth. The water specific gravity was 1.005 and the average water temperature was 84°F (28.9°C).

TRIAL PROCEDURES

M/V BENYAURD, fifteen barges to be used in the tow, and an anchor barge arrived at the trial site on 28 July 1985. Throughout the night the tow was assembled and final equipment checks were made in preparation for the maneuvering trials. The procedures followed for each type of maneuver performed during the subject trials are described below.

SPEED/RPM CALIBRATION

The primary objective of the speed/rpm calibration was to establish the speed/rpm relationship of the tow configuration so that shaft rpm could be used as a reference for achieving the desired approach speed for the various maneuvers. In general, each data point on the speed/rpm curve was derived from the average of two steady four minute runs in reciprocal directions in order to cancel the effects of water current. No throttle changes were made during each run and rudder movements were kept to a minimum.

TURNING MANEUVERS

A series of turning maneuvers were completed in order to determine the dynamic and the steady turning characteristics of the tow configuration. Each turning maneuver was preceded by a one minute steady approach after which the command was given for the rudder to be moved promptly to the scheduled angle. (Rudder angle indicators were temporarily installed in the pilot house to facilitate the conduct of these trials.) No further rudder or throttle movements were made until the maneuver was completed. Most turning maneuvers were terminated after heading changes of 180 degrees or less, but several turning maneuvers continued until the heading had changed by 540 degrees. Heading changes of 540 degrees were necessary to determine the magnitude and direction of the local water current.

HORIZONTAL OVERSHOOT MANEUVERS

Horizontal overshoot maneuvers were conducted to quantify the degree of responsiveness exhibited by the tow to changes in rudder angle. The overshoot in heading, resulting from a reversal of rudder angle to stop the ship from turning, is a means of characterizing the degree of ship control possible through use of the steering or flanking rudders.

Once the tow was steady on course with rudders amidships, the proper rudder was moved to the scheduled value and the throttle was moved to the desired engine order. The rudder angle was maintained until a predetermined change of heading from the base course was obtained. The rudder was then shifted a like amount to the opposite side of amidships and held until the same

change of heading on the opposite side of the base course was obtained. The rudder was maneuvered in this manner until all scheduled rudder movements were completed.

ACCELERATION AND DECELERATION MANEUVERS

Acceleration and deceleration trials were conducted to determine the starting and stopping characteristics (distance and time) of the tow relative to various initial and terminal conditions. Acceleration and deceleration runs were preceded by 60 seconds of steady approach. At EXECUTE the controls were moved to the final engine order and held until steady conditions were reached.

LATERAL MOTION MANEUVERS

Lateral motion trials were conducted to determine the towboat's ability to induce a lateral motion on the tow configuration. The motions were induced by applying a combination of ahead and astern engine throttlings coupled with the proper main and flanking rudder deflections.

All lateral motion maneuvers began after 60 seconds of data had been collected with the tow dead-in-the-water. At EXECUTE, or the start of the run, the engine controls were moved to the scheduled positions, and then the rudder controls were moved to the scheduled positions. Both the engine and rudder controls remained unchanged until the speed of the tow reached a constant value and the run was terminated.

TRIAL RESULTS

GENERAL

Due to a combination of favorable weather, minimal interference from local boat traffic, and the enthusiastic cooperation of all personnel involved in the trials, all maneuvers scheduled for the baseline tow/barge configuration were completed within three days. As a result, the tow/barge configuration was changed twice more and data were obtained for a "long" six barge tow and a "wide" six barge tow.

Results of the subject maneuvering trials are presented as X/Y position plots, change of heading versus time plots, and rudder movement versus time plots. Position plots were constructed using the X and Y coordinates computed

by either the bow or the stern tracking console. (The better of the bow or the stern tracks is shown in this document.) Bow and stern X/Y coordinate data computed by the tracking consoles, as well as the raw range data are recorded on the previously referenced nine track magnetic tape. (See Appendix C.)

Occasional shifts in the track of the tow configuration are apparent in a number of the plots and are due to the temporary loss of the return signal from one or two of the reference stations. These shifts are generally on the order of 20 yards and are likely attributable to inaccuracies associated with the methods used to locate each reference station (see Appendix A). In retrospect, better site determination, through a commercial survey, would have reduced the magnitude of the track shift due to range loss. It is doubtful, however, that such a survey was feasible considering the available trial preparation time and the level of funding. An alternate method of determining X/Y position is presented in Appendix D.

Failure to obtain a minimum of two transponder responses during a given measurement cycle resulted in computed X/Y coordinate values of zero. These data have been omitted from the enclosed plots.

The loss of one or two transponder responses occurred in approximately 30 percent of the runs conducted with the largest percentages of dropout occurring on the second and third days of testing. During the trials, low battery voltage was noted at one reference station and one reference transponder had to be replaced. Additionally, one reference station support was tilted by high winds and was not detected for an extended period of time. The use of additional shore station personnel for more complete surveillance of each reference station would have permitted quicker response to such problems thus reducing the amount of range dropout.

Overall, the performance of the two tracking systems and the successful measurement of towboat heading provide ample means of accurately determining both the position and orientation of the towboat/tow configuration throughout the testing period. Fairing of the tracking data may, however, be necessary in a few of the runs due to excessive dropout.

SPEED/RPM CALIBRATION

Results of the speed/rpm calibration runs are presented in Figure 4 and in Table 4. For the baseline configuration, speeds of 4.9 knots and 5.8 knots were obtained with average shaft rpm values of 172.4 and 198.2, respectively. Only a single data point, 2.9 knots at 209.6 rpm, was obtained in the astern direction for the baseline condition. Due to a concern for the time available for the trials, it was decided not to obtain an additional astern speed point.

For configuration L (six barges, long), shaft rpm values of 101.2 and 181.2 resulted in speeds of 3.6 knots and 6.6 knots, respectively, in the ahead direction. In the astern direction an average shaft rpm of 101.0 resulted in a speed of 1.9 knots. Again, due to a concern for time, only one additional run was conducted in the astern direction for configuration L. This single data point is plotted in Figure 4 and is used to construct the speed/rpm curve. Use of a single point for this curve is considered valid since the trial data indicate that insignificant water current existed at the test site.

Two speed points were measured in both the ahead and the astern directions for configuration W (six barges, wide). In the ahead direction, shaft rpm values of 89.2 and 145.4 resulted in speeds of 3.0 knots and 4.9 knots, respectively. In the astern direction, speeds of 1.4 knots and 2.6 knots were measured for rpm values of 87.6 and 145.3.

TURNING MANEUVERS

Six steady turning maneuvers were conducted in the ahead direction for the baseline tow configuration. The results of these turning maneuvers are shown in Figures 5 through 18. Run 2000 was interrupted after a heading change of approximately 45 degrees due to an instrumentation malfunction. Data collection was subsequently re-started and is presented as Run 2002 in Figures 7 and 8.

Runs 2000 through 2120 indicate that advance and transfer decrease with increasing rudder and that the baseline tow/barge configuration turns essentially the same to the left or to the right. These runs also indicate that the tow turning characteristics are slightly speed dependent as advance and transfer decrease as approach speed increases. The results of these maneuvers are also shown in Table 5.

The advance, transfer, and tactical diameter data shown in Table 5 were obtained from plots of the movement of the longitudinal center of gravity of each tow/barge flotilla as opposed to the track of the bow or stern as shown in this document. A center of gravity (CG), 524 feet (159.7 meters) aft of the bow was used for the baseline configuration and a CG of 347 feet (105.8 meters) aft of the bow was used for the long configuration. For the wide configuration a CG of 235 feet (71.6 meters) aft of the bow was used. Each CG was based on an estimation of the summation of weights divided by the summation of moments from the bow. The towboat CG, 71 feet (21.6 meters) aft of the bow, was provided by Jeffboat, Inc.

The turning characteristics listed in Tables 5 and 6 were determined in accordance with Appendix E. The circle plots have not been drift corrected.

The results of two steady astern turning maneuvers are shown in Figures 19 through 24. These runs also indicate the effectiveness of increased rudder on turning characteristics as both advance and transfer decrease by more than 300 yards (274 meters) as rudder angle is increased from 20 degrees right to 35 degrees right. The data collection system stopped and was re-started during Run 2140.

Figures 25 through 28 indicate the results of two transient turning maneuvers. Run 2090 exhibited a larger advance since the tow was at a greater speed during the initial portion of the maneuver. Once the tow configuration reaches a steady condition, the turning diameters are similar as evidenced by Table 5.

Runs 2110 and 2115, Figures 29 through 32, represent coasting maneuvers from an initial speed of 5.8 and 5.9 knots, respectively. Only four degrees deviation from the base course is noted while coasting with 35 degrees right rudder, (Run 2110), as opposed to fifteen degrees deviation from base course when 35 degrees left rudder is used (Run 2115). (The staircase effect, present in Figure 30, is due to the resolution of the 12-bit analog to digital converter used during the trials.) Figures 33 and 34 indicate the results of Run 2117, an accelerating turn from All Stop.

The results of three astern transient turning maneuvers are shown in Figures 35 through 40.

Four turning maneuvers were conducted using the long configuration from the ahead direction without using a change in engine order. Position plots and change of heading curves for these runs are shown in Figures 41 through 48 and are tabulated in Table 6. Runs L2000 through L2040 indicate that smaller advances and transfers are obtained with increased rudder angles. Run L2010 was repeated because it was felt the high winds encountered from a passing storm had affected the results of the turn. This is seen in the greater advance obtained when compared to Run L2011 which was run in diminished winds. During Run L2040 a wind shift was noted from the northeast toward the south.

Three astern turning maneuvers were conducted in the long configuration without a change in engine order. These runs are shown in Figures 49 through 54 and tabulated in Table 6. These turns were conducted through 90 degrees change of heading.

An accelerating turn from All Stop was conducted using a full right steering rudder and is shown in Figures 55 and 56.

With the tow/barge reconfigured into the wide tow, three ahead turns were conducted without use of a change in engine order. These runs are shown as track plots and change of heading curves in Figures 57 through 62. In runs W2000 through W2040, it can be seen that the same trend develops as increasing rudder angles produce smaller advances and transfers.

While still in the wide tow configuration, three steady astern turns were conducted. These are shown as track plots and change of heading curves in Figures 63 through 68. As the speed increased, the advance and transfer decreased as can be seen in Table 6. An accelerating turn was conducted from All Stop to determine the turning effects from a dead-in-the-water situation. This turn is shown in Figures 69 and 70.

HORIZONTAL OVERSHOOT MANEUVERS

While in the baseline tow configuration several overshoot maneuvers were conducted using ahead and astern approaches. Some runs were conducted with no throttle changes while other runs included a change in engine order at the first execute command. Figures 71 through 74 show the track plot and rudder and heading curves for the runs conducted without a change in engine order. A summary of the overshoot angles and times, determined as shown in Appendix F,

can be seen in Table 7. For the steady speed runs, the overshoot angles and times are greater for the greater rudder angles.

Figures 75 and 76 show the track plot and the rudder and heading curves for the astern steady speed horizontal overshoots. Figures 77 through 84 show the results of four overshoot maneuvers and the effects of an increasing or decreasing engine order at the first execute. The results are also tabulated in Table 7. An increase in engine order tends to decrease the times between successive executes, however, no significant change was observed in the overshoot angles of runs using similar rudder movements.

The astern horizontal overshoot maneuvers conducted using a change in engine order at execute are shown in Figures 85 through 94 and are summarized in Table 7. Data collection was interrupted during Run 3160 due to a computer malfunction. The system was subsequently re-started and the maneuver was continued and labeled as Run 3161 on the 9-track tape. Thus, only a portion of the characteristics of Run 3160 are shown in Table 7.

A series of horizontal overshoot maneuvers were also conducted with the long and wide tow configurations. The results of these maneuvers using the long barge/tow configuration are presented in Figures 95 through 100. The results of the maneuvers using the wide barge/tow configuration are presented in Figures 101 through 110. A tabulated summary of the overshoots is shown in Table 8.

The horizontal overshoots conducted with the long tow configuration were steady speed runs only. Run L3010, aborted because of a missed execute mark after the third execute, was re-run as Run L3011. The horizontal overshoot maneuvers conducted with the wide tow consisted of only steady speed runs. The runs similar to those conducted with the baseline tow using a change in engine order at the first execute were omitted due to time constraints.

Run W3100 was finexed after the second execute when the tow/barge was not responding to the rudder. It was felt that the tow was in an unstable condition and would not return to its baseline course. Therefore, Run W3101 was conducted under the same approach conditions as Run W3100. At execute, however, an initial right rudder was used instead of left rudder. The tow did respond to the second execute, but continued past 70 degrees change of heading after the third execute. At this time, the tow was felt to be unstable and the

run was finexed. After this run an investigation into the instability found the towboat to be offset from the centerline 4 inches. This offset may have contributed to the instability problem when going astern and executing a left checking rudder.

ACCELERATION AND DECELERATION MANEUVERS

Several acceleration and deceleration maneuvers were conducted in each tow configuration. These maneuvers are presented as track plots only. The baseline tow maneuvers are presented in Figures 111 through 119. The long tow/barge configuration acceleration and deceleration maneuvers are represented in Figures 120 through 125. Figures 126 through 130 show the track plots for the acceleration and deceleration maneuvers conducted while in the wide tow configuration.

LATERAL MOTION MANEUVERS

A series of lateral motion, twisting and checking turn maneuvers were conducted in each of the tow configurations. These results are presented as track plots in Figures 131 through 138.

CONCLUSIONS

Data obtained during the tow/barge maneuvering trials appear to be adequate for use with analytical methods in determining the hydrodynamic coefficients of a tow/barge flotilla operating in shallow water. The subject trials have thus provided a needed source of full-scale data which should augment the current understanding of tow/barge flotilla maneuvering characteristics and should provide useful information for the development of future trials.

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The authors wish to express their appreciation for the cooperation and hospitality extended to the DTNSRDC trials personnel by Captain Muirhead and the crew of the M/V BENYAURD. A special note of thanks is due to the Chief Engineer, Wayne McMaster and the engine department for their assistance and engineering support throughout the installation and trial period. The professionalism exhibited by the crew along with their interest in the project contributed significantly to the successful completion of the maneuvering trials.

The authors would also like to acknowledge Lieutenant Dave Alley, United States Coast Guard; Dr. Larry Daggett, United States Army Corps of Engineers; and Dave Walden, DTNSRDC; for their assistance, advice, and enthusiasm in the preparation and execution of the subject trials. The United States Coast Guard, New Orleans District, is also to be commended for their support at the test site during the trials.

BASELINE TOW CONFIGURATION		
SYMBOL	DESCRIPTION	LOCATION
○	FWD TRACKING ANTENNA	225.5 ft (68.7 m) AFT OF BOW, CENTERLINE
⦰	AFT TRACKING ANTENNA	1013.0 ft (308.8 m) AFT OF BOW, CENTERLINE
◆	GUARD POLE	56.5 ft (17.2 m) AFT OF BOW, 17.5 ft (5.3 m) STBD OF C.L.
◇	FWD EM LOG PROBE	238.0 ft (72.5 m) AFT OF BOW, 17.5 ft (5.3 m) STBD OF C.L.
◇̸	AFT EM LOG PROBE	509.5 ft (155.3 m) AFT OF BOW, 17.5 ft (5.3 m) STBD OF C.L.
△	WIND ANEMOMETER	417.5 ft (127.3 m) AFT OF BOW, CENTERLINE
□	INSTRUMENTATION SHED	294.5 ft (89.8 m) AFT OF BOW, CENTERLINE

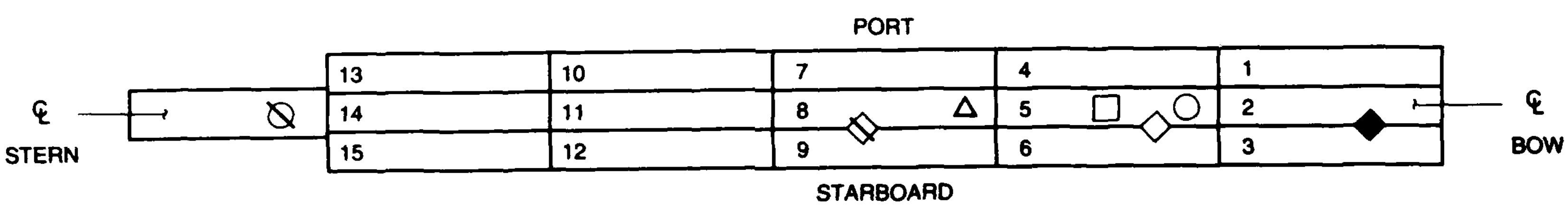

Figure 1 - Tow Configuration B

LONG TOW CONFIGURATION, "L"		
SYMBOL	DESCRIPTION	LOCATION
○	FWD TRACKING ANTENNA	30.5 ft (9.3 m) AFT OF BOW, 17.5 ft PORT OF C.L.
⦰	AFT TRACKING ANTENNA	622.5 ft (189.7 m) AFT OF BOW, CENTERLINE
◇	FWD EM LOG PROBE	43.0 ft (13.1 m) AFT OF BOW, CENTERLINE
◇̸	AFT EM LOG PROBE	314.0 ft (95.7 m) AFT OF BOW, CENTERLINE
△	WIND ANEMOMETER	222.5 ft (67.8 m) AFT OF BOW, 17.5 ft (5.3 m) PORT OF C.L.
□	INSTRUMENTATION SHED	99.5 ft (30.3 m) AFT OF BOW, 17.5 ft (5.3 m) PORT OF C.L.

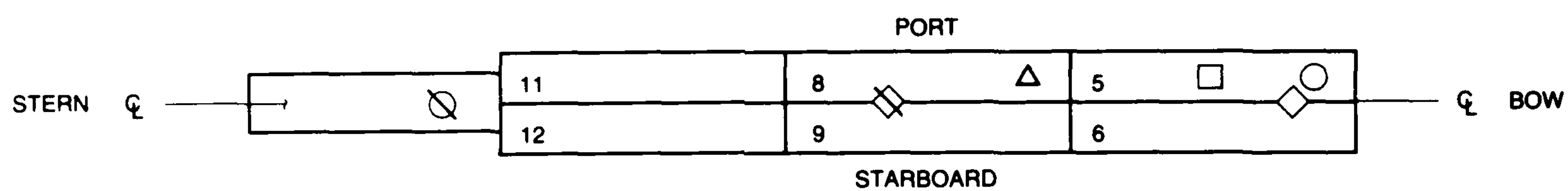

Figure 2 - Tow Configuration L

WIDE TOW CONFIGURATION, "W"		
SYMBOL	DESCRIPTION	LOCATION
○	FWD TRACKING ANTENNA	30.5 ft (9.3 m) AFT OF BOW, CENTERLINE
⊘	AFT TRACKING ANTENNA	426.0 ft (129.8 m) AFT OF BOW, CENTERLINE
◇	FWD EM LOG PROBE	43.0 ft (13.1 m) AFT OF BOW, 17.5 ft (5.3 m) STBD OF C.L.
◇̸	AFT EM LOG PROBE	313.5 ft (95.6 m) AFT OF BOW, 17.5 ft (5.3 m) STBD OF C.L.
△	WIND ANEMOMETER	222.5 ft (67.8 m) AFT OF BOW, CENTERLINE
□	INSTRUMENTATION SHED	99.5 ft (30.3 m) AFT OF BOW, CENTERLINE

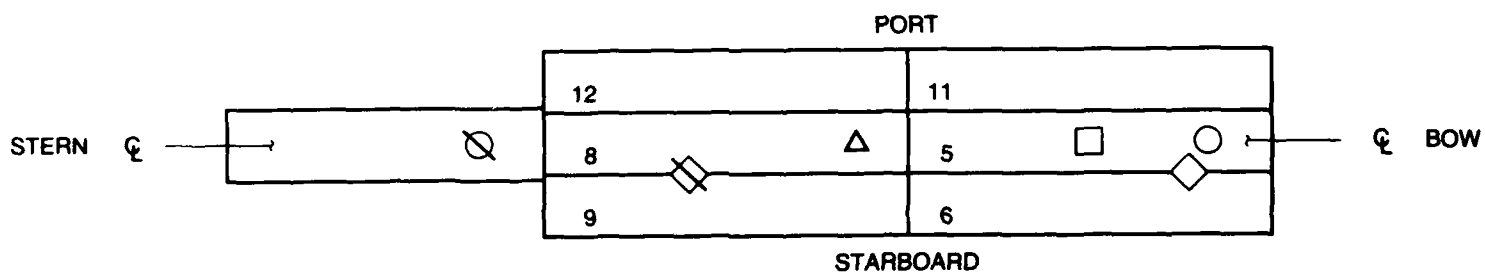

Figure 3 - Tow Configuration W

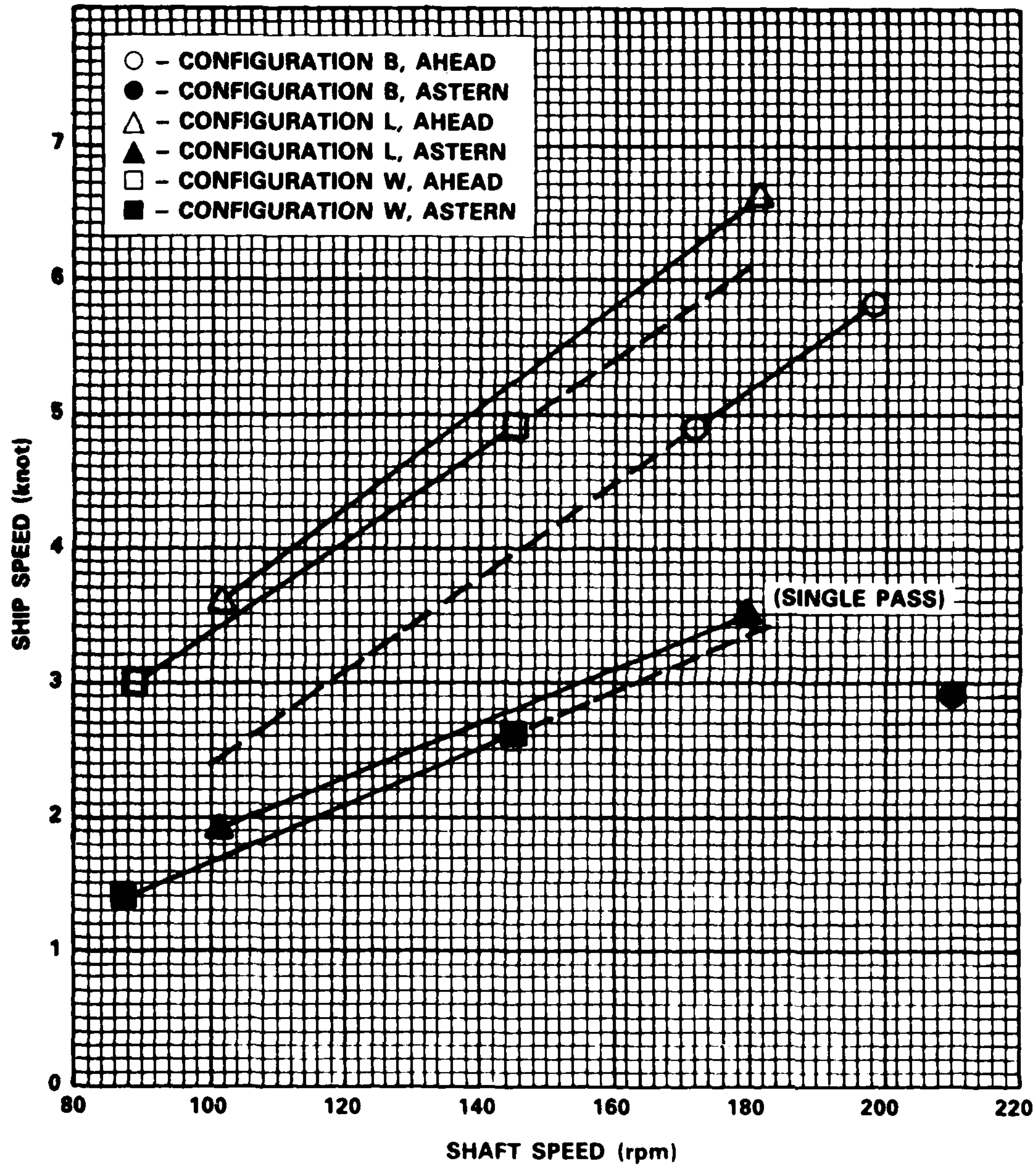

Figure 4 - Speed versus RPM Calibration Curves for Tow Configurations B, L, and W

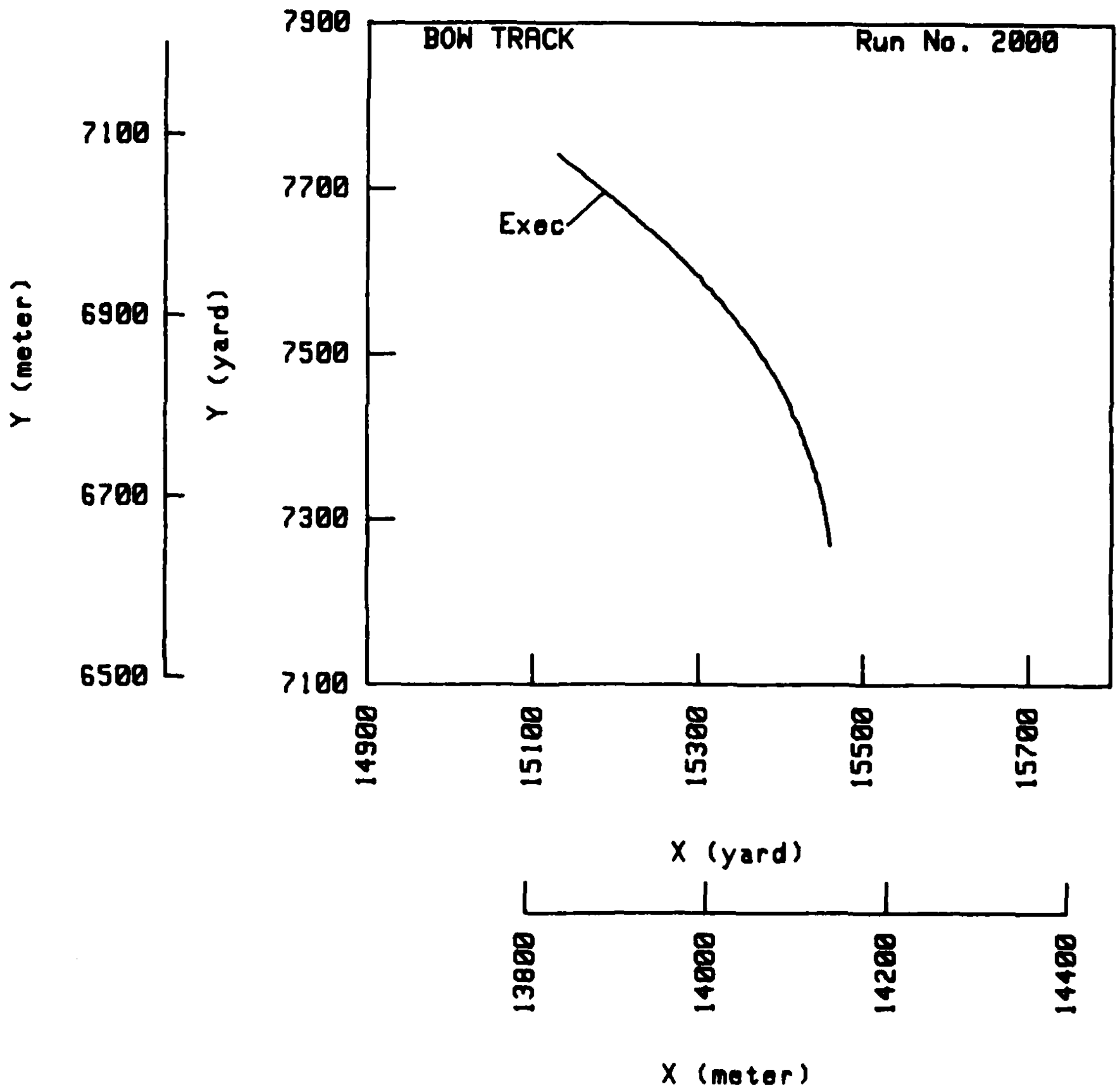

Figure 5 - Position Plot for Half Ahead, 35 Degrees Right Rudder Turning Maneuver (Run 2000)

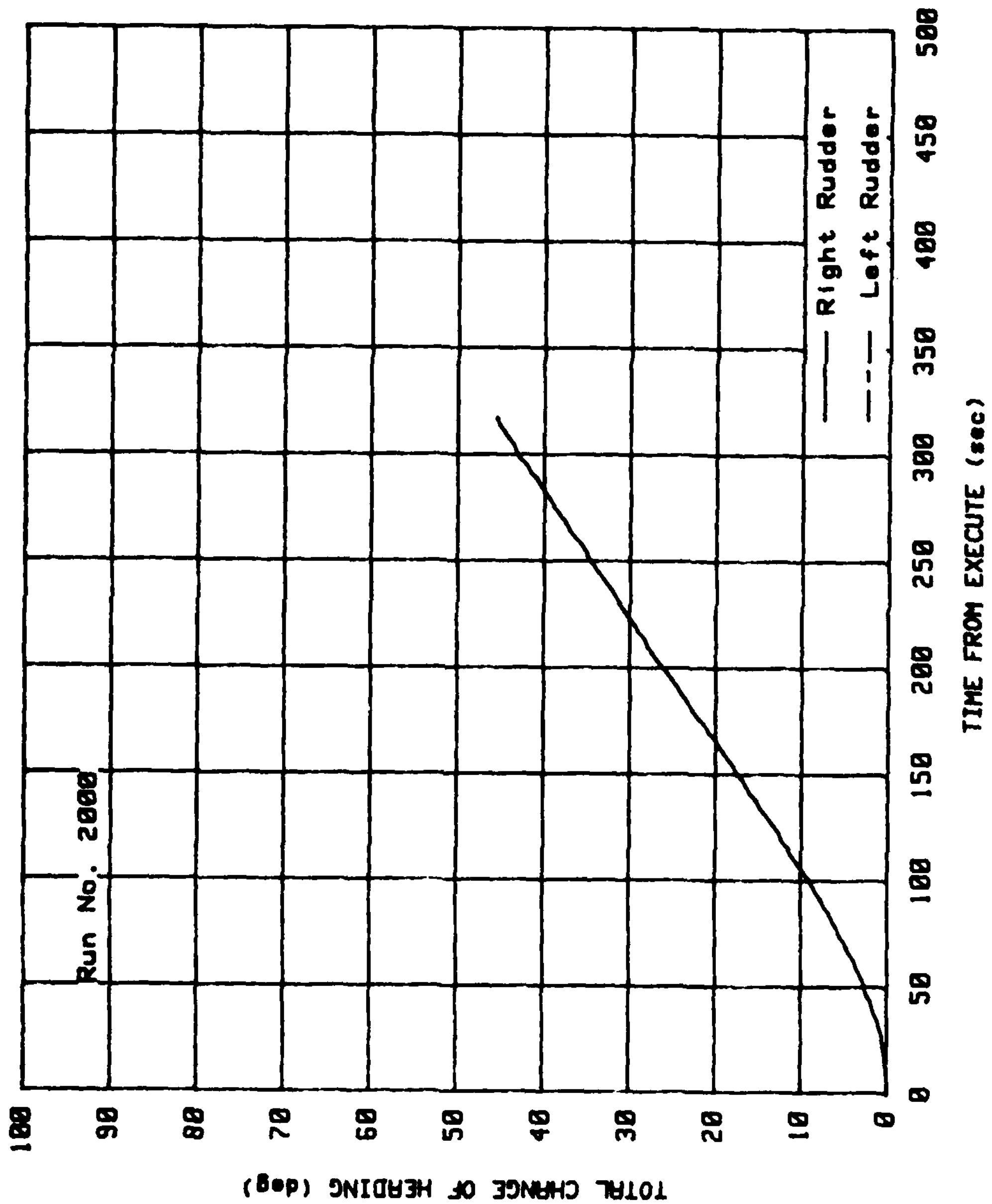

Figure 6 - Change of Heading Plot for Half Ahead, 35 Degrees Right Rudder Turning Maneuver (Run 2000)

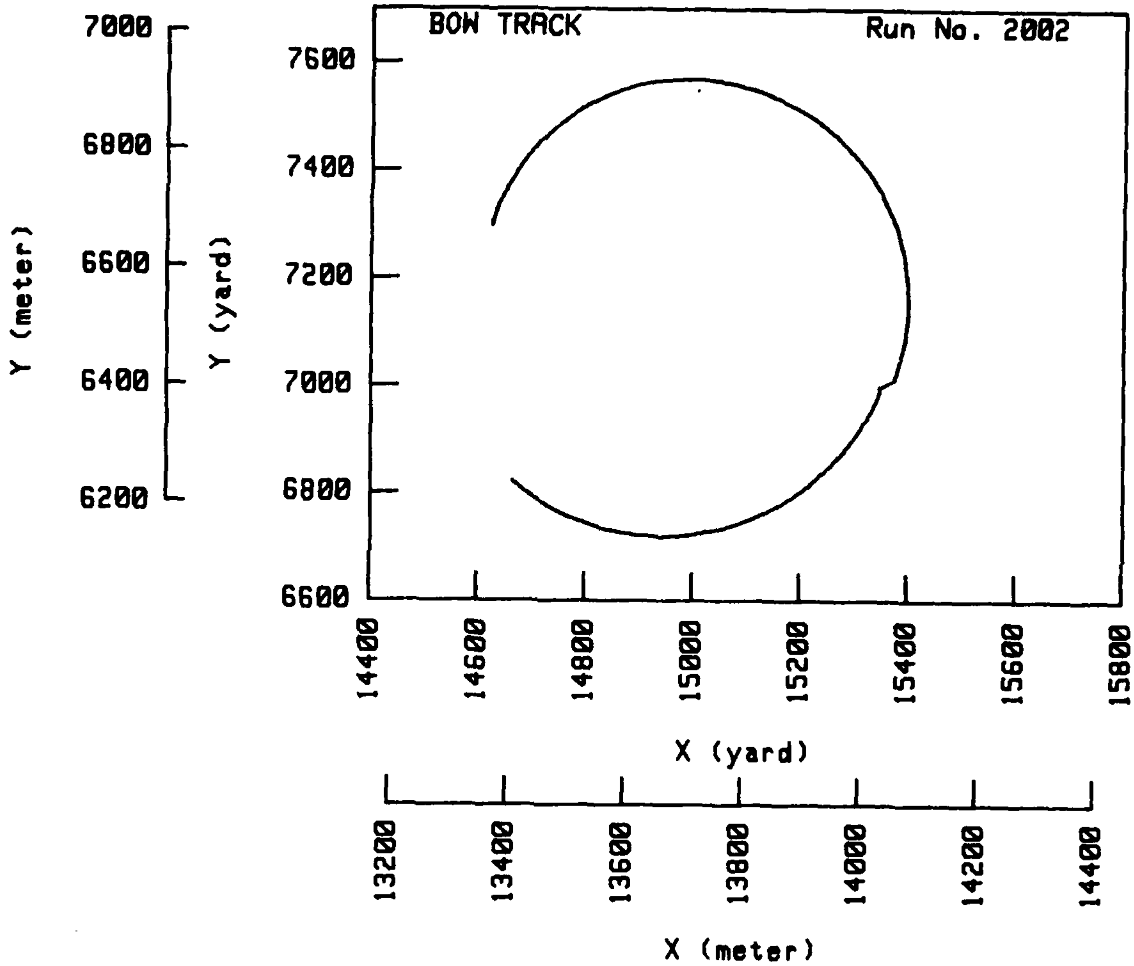

Figure 7 - Position Plot for Half Ahead, 35 Degrees Right Rudder Turning Maneuver (Run 2002, Continuation of Run 2000)

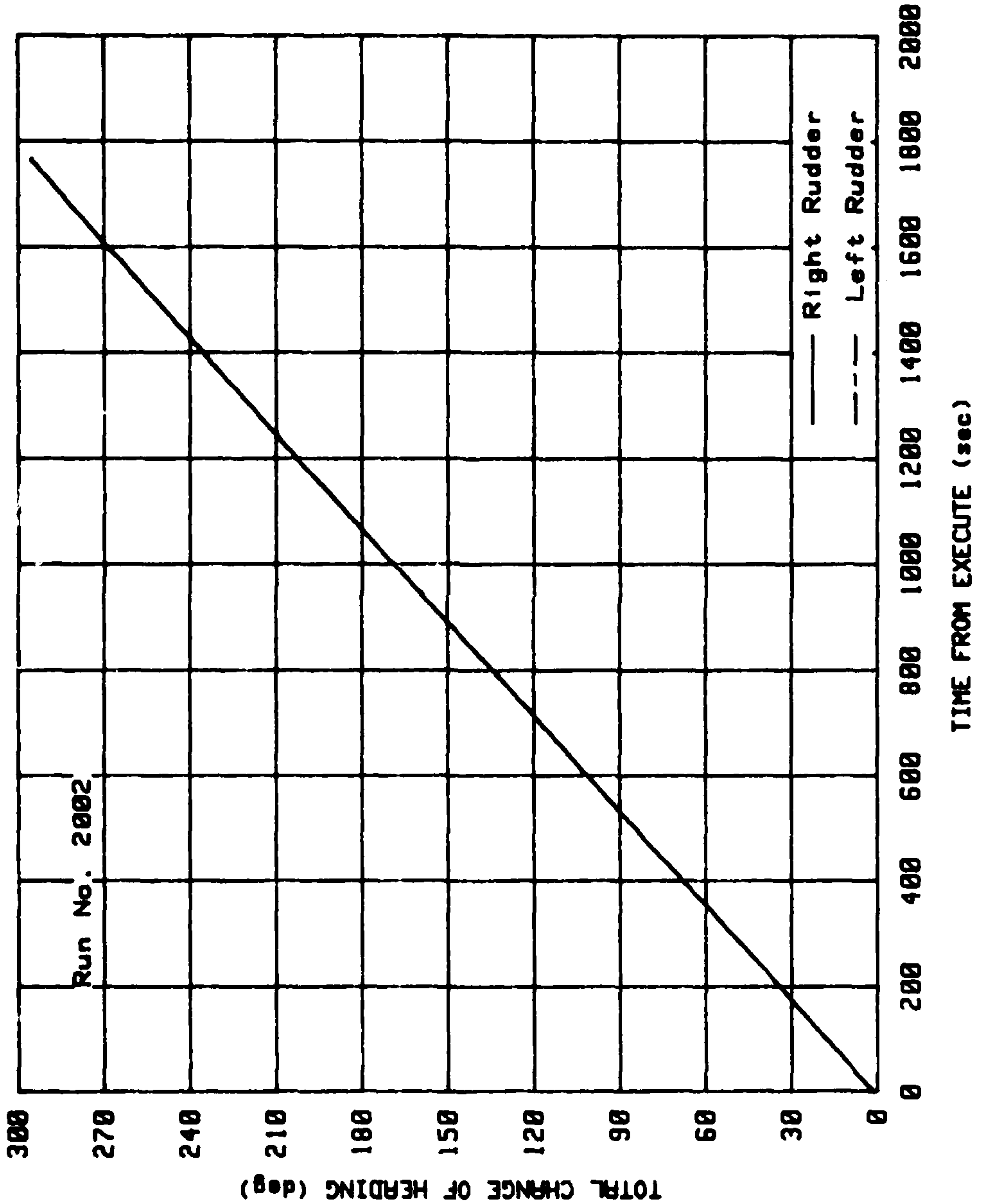

Figure 8 - Change of Heading Plot for Half Ahead, 35 Degrees Right Rudder Turning Maneuver (Run 2002, Continuation of Run 2000)

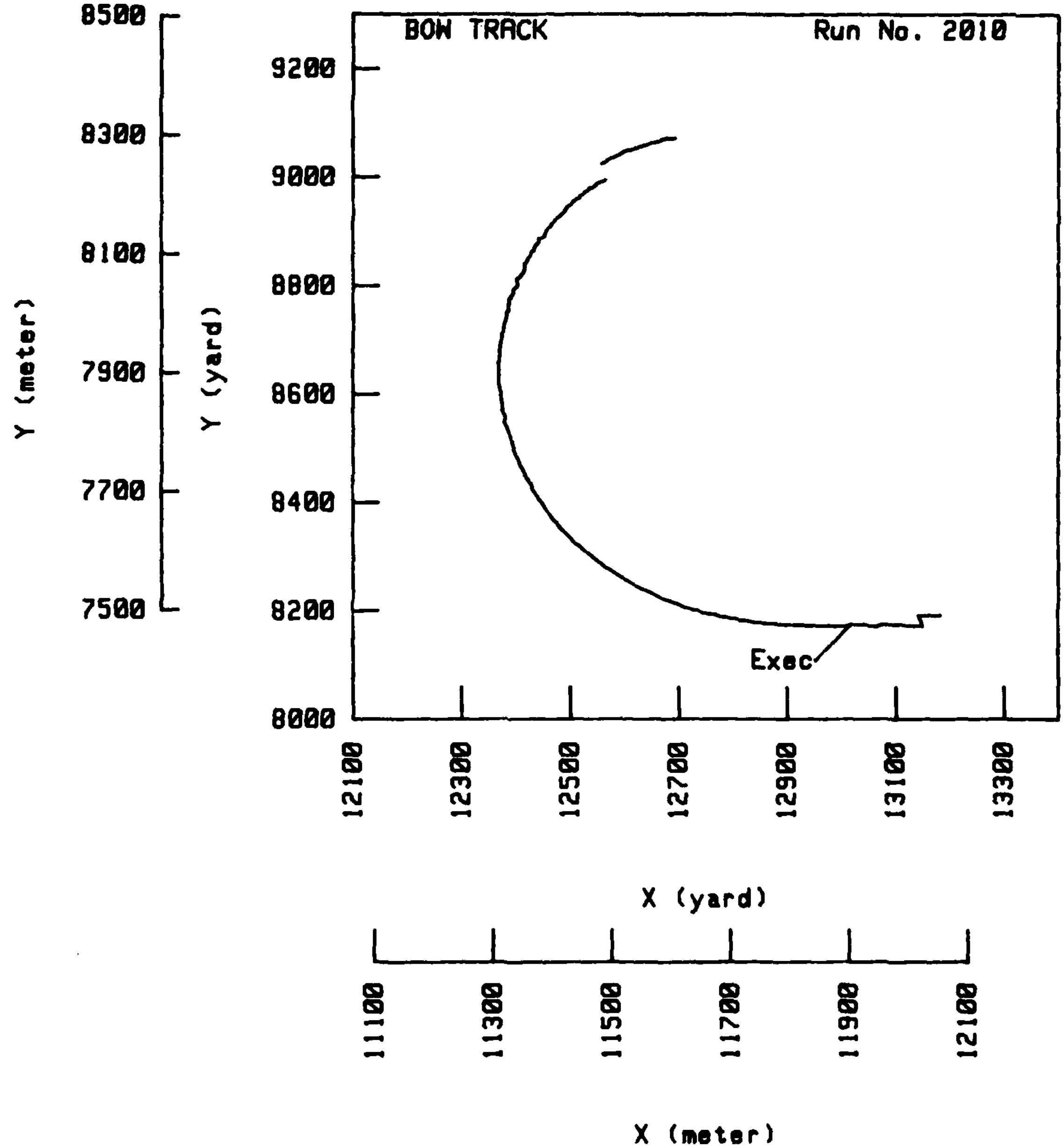

Figure 9 - Position Plot for Full Ahead, 35 Degrees Right Rudder Turning Maneuver (Run 2010)

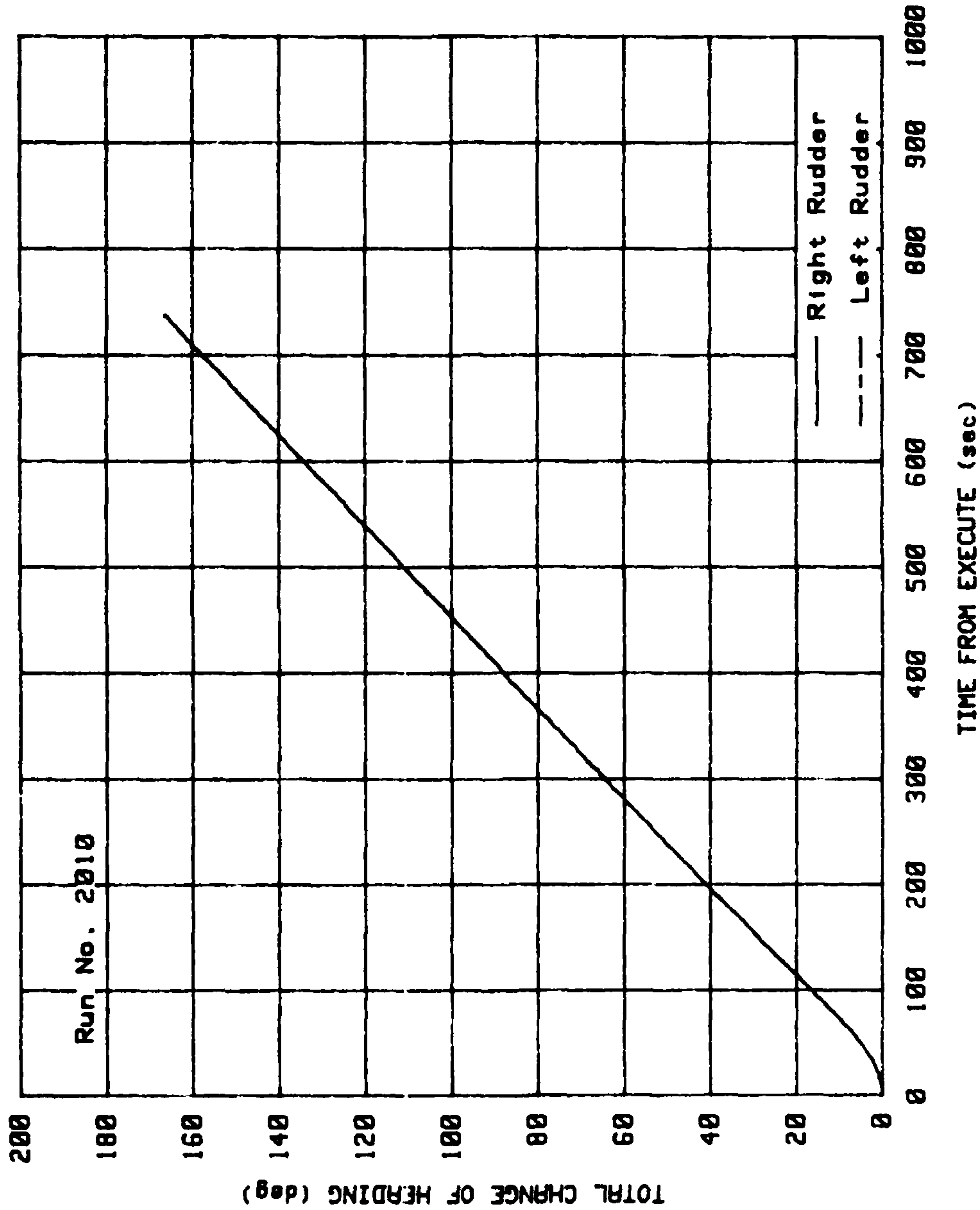

Figure 10 - Change of Heading Plot for Full Ahead, 35 Degrees Right Rudder Turning Maneuver (Run 2010)

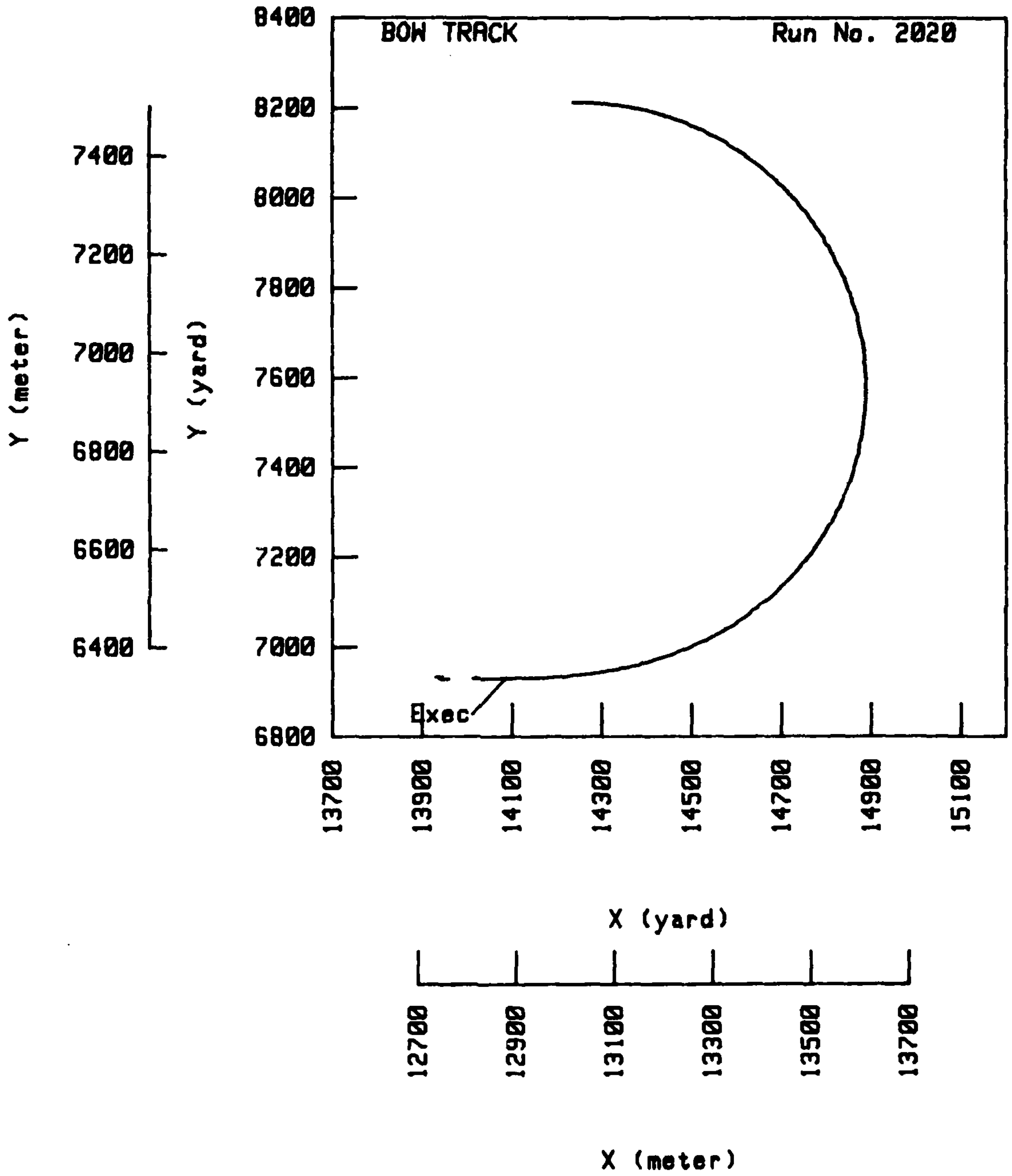

Figure 11 - Position Plot for Full Ahead, 25 Degrees Left Rudder Turning Maneuver (Run 2020)

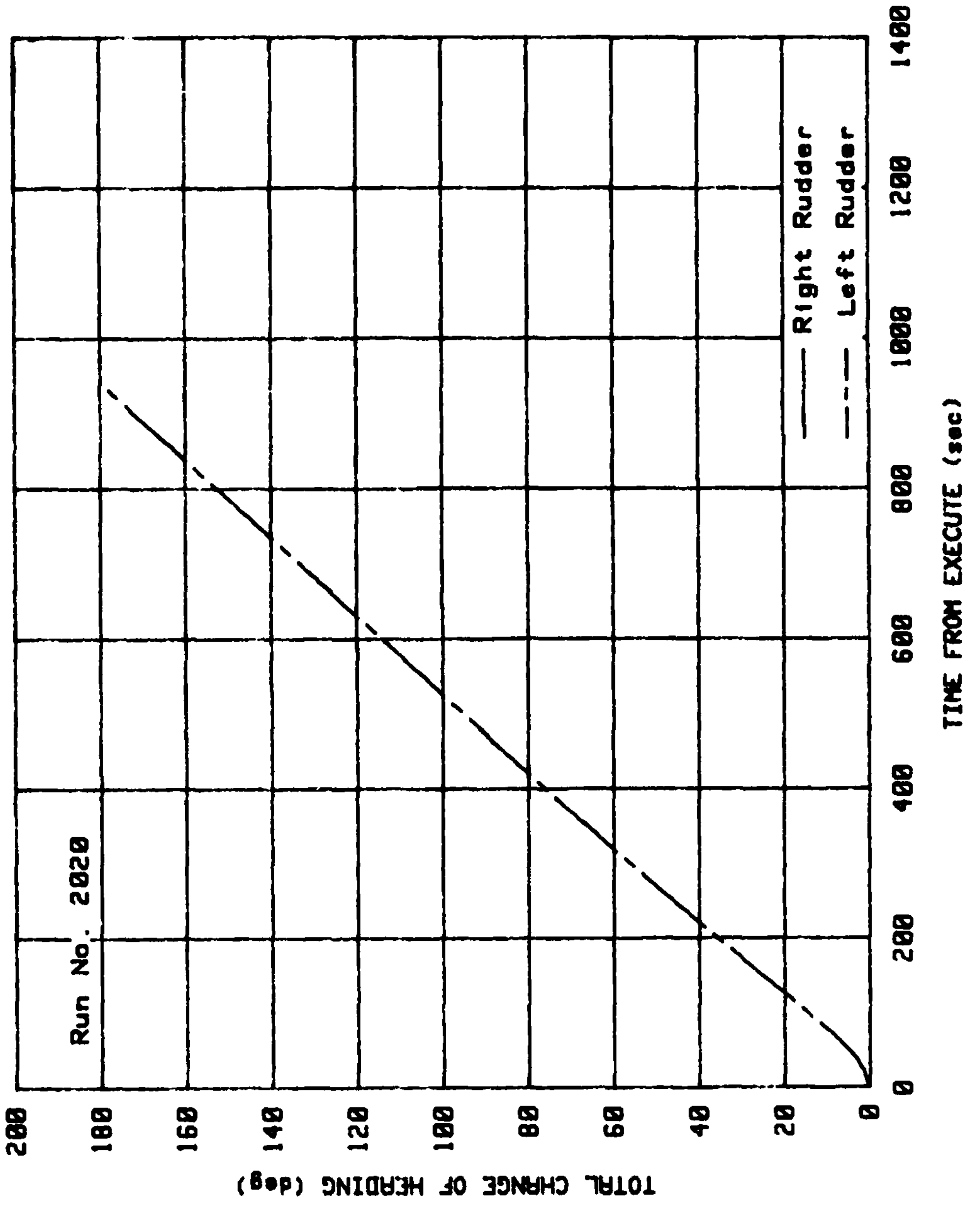

Figure 12 - Change of Heading Plot for Full Ahead, 25 Degrees Left Rudder Turning Maneuver (Run 2020)

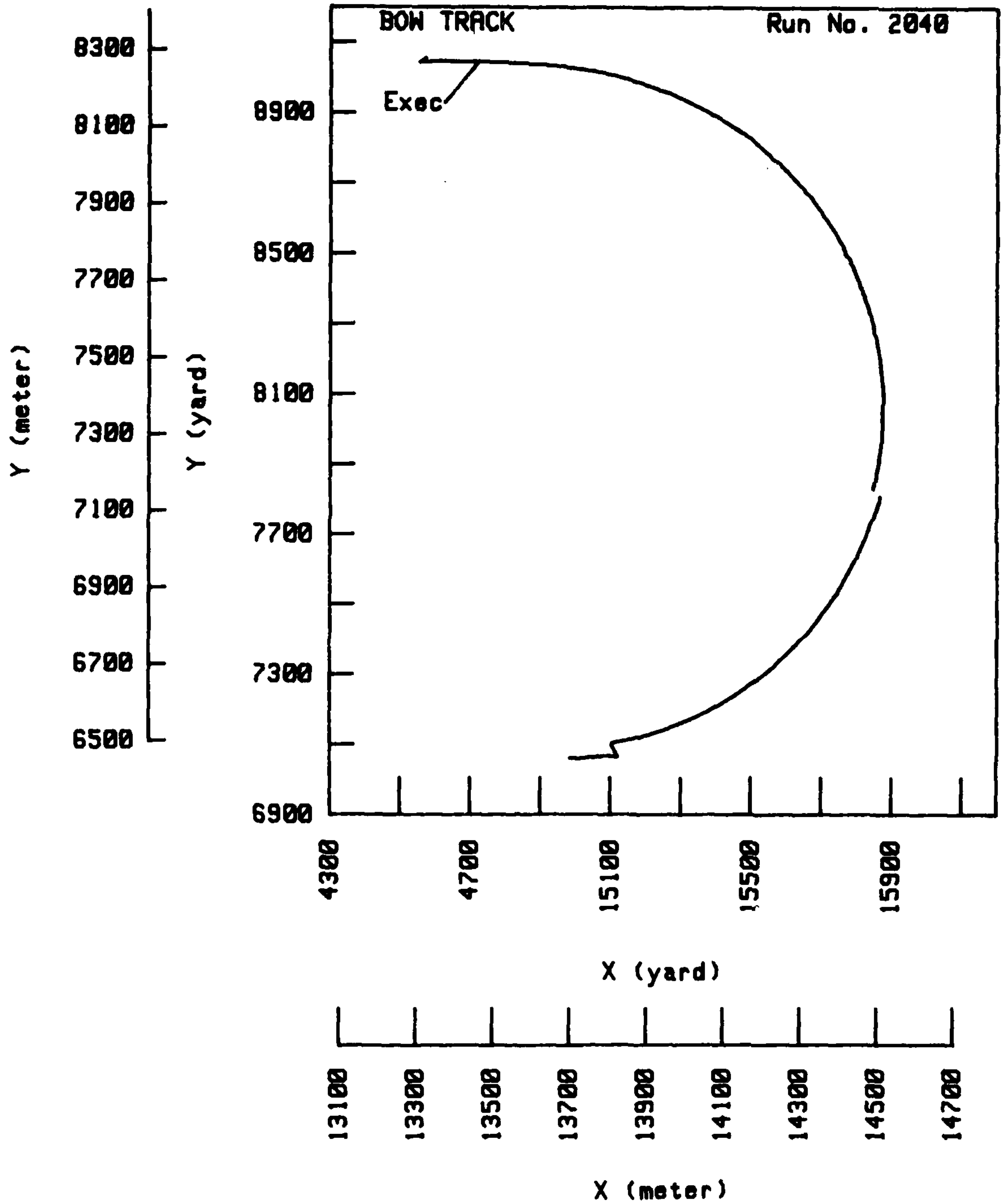

Figure 13 - Position Plot for Full Ahead, 15 Degrees Right Rudder Turning Maneuver (Run 2040)

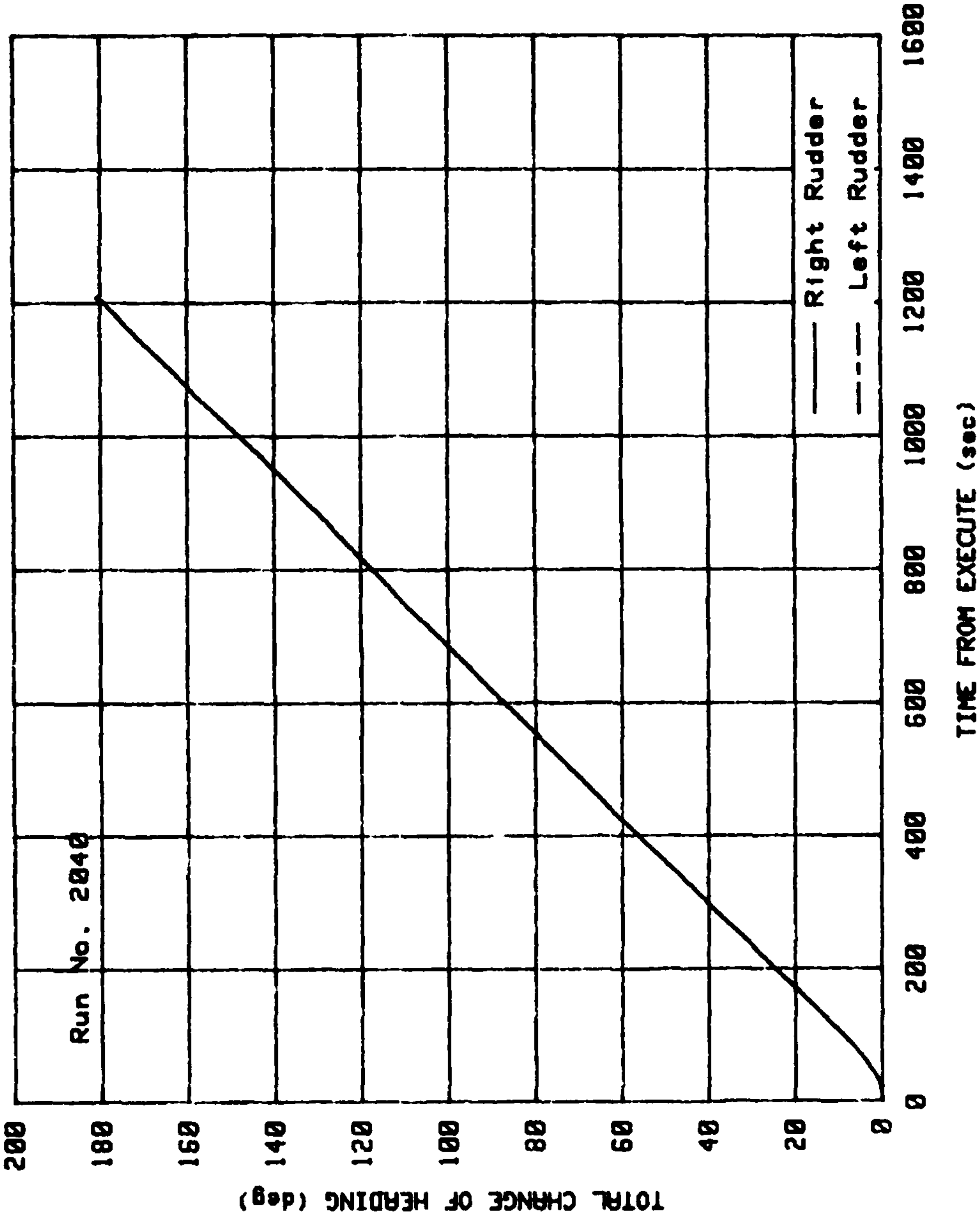

Figure 14 - Change of Heading Plot for Full Ahead, 15 Degrees Right Rudder Turning Maneuver (Run 2040)

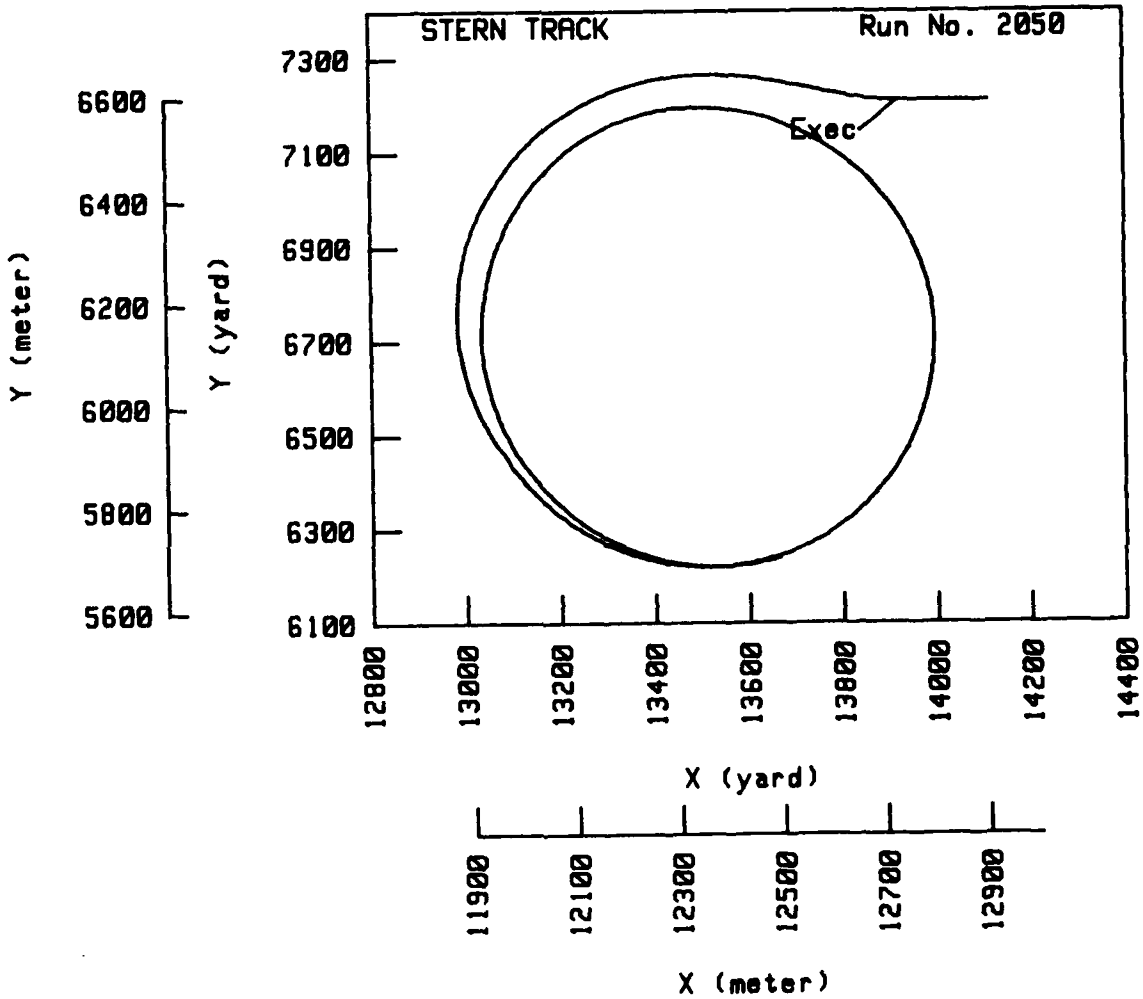

Figure 15 - Position Plot for Full Ahead, 35 Degrees Left Rudder Turning Maneuver (Run 2050)

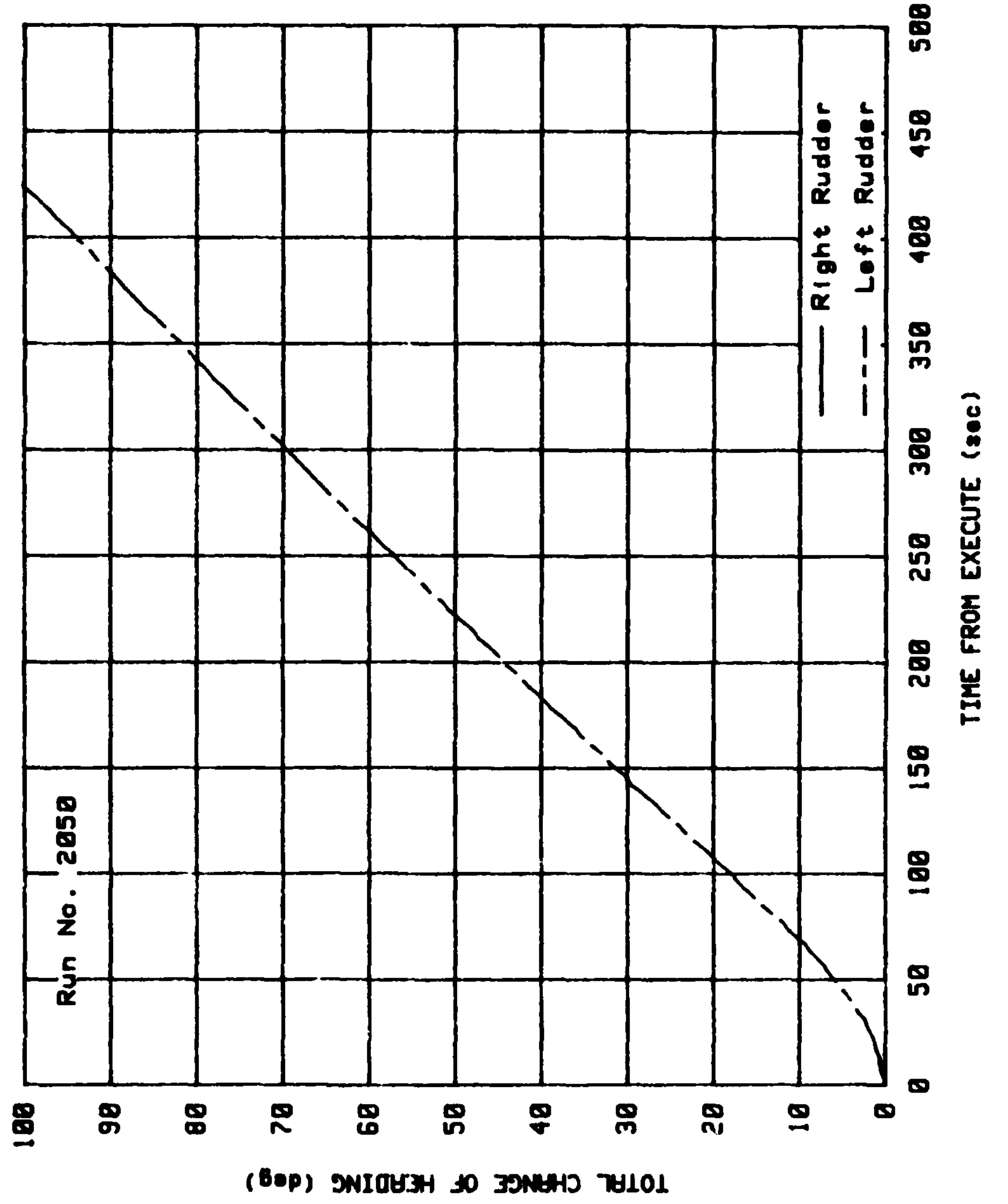

Figure 16 - Change of Heading Plot for Full Ahead, 35 Degrees Left Rudder Turning Maneuver (Run 2050)

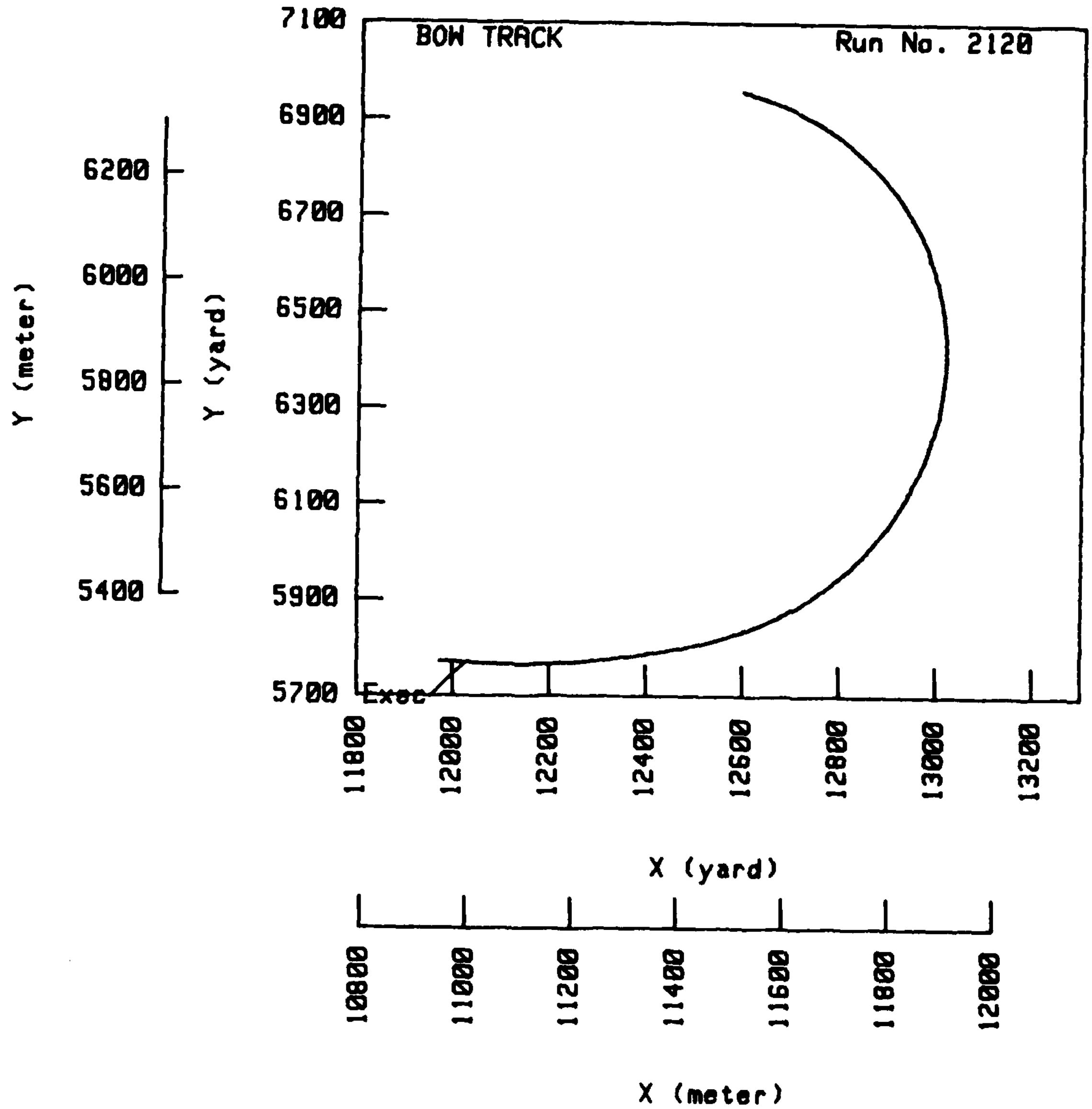

Figure 17 - Position Plot for Half Astern, 35 Degrees Right Rudder Turning Maneuver (Run 2120)

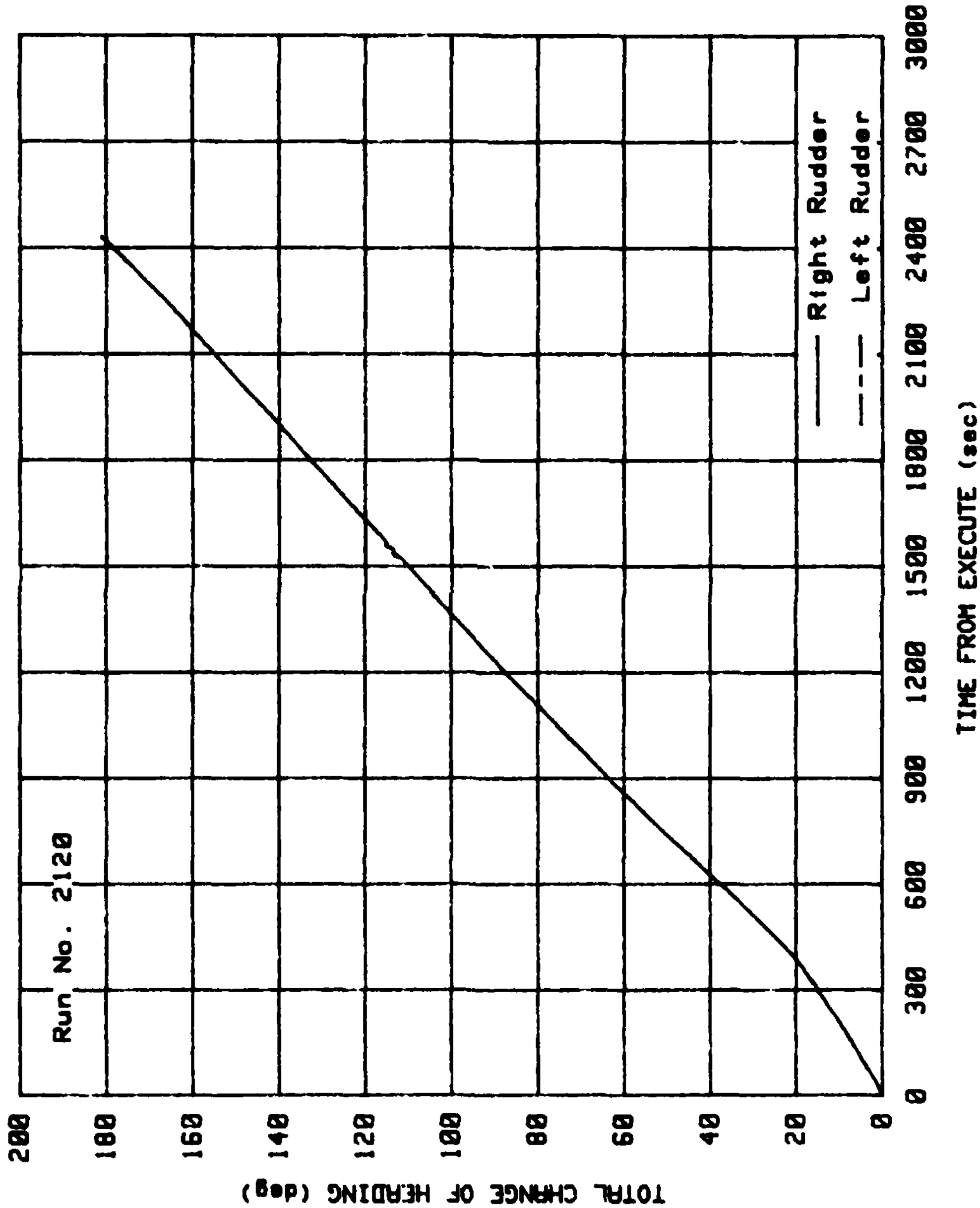

Figure 18 - Change of Heading Plot for Half Astern, 35 Degrees Right Rudder Turning Maneuver (Run 2120)

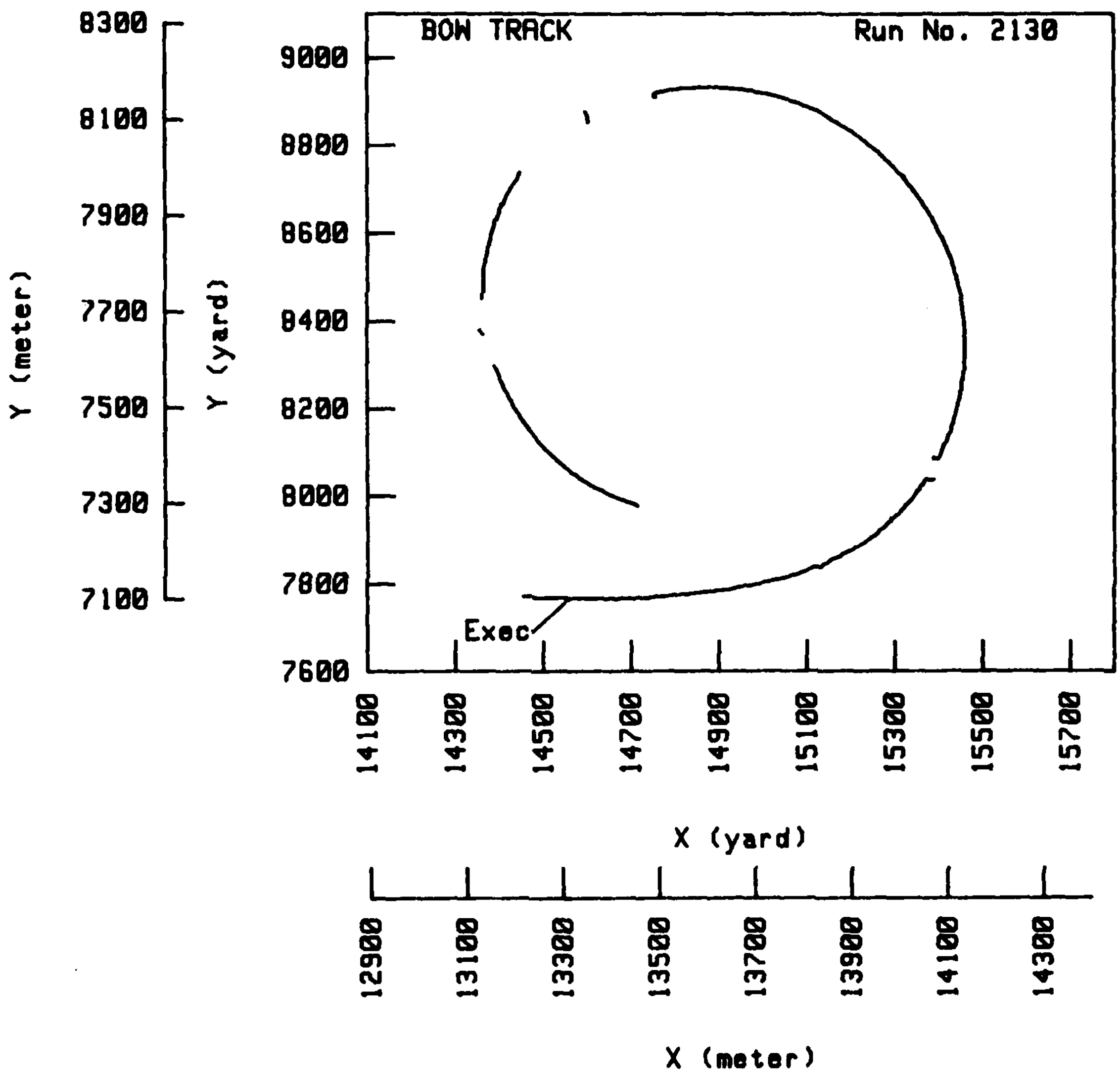

Figure 19 - Position Plot for Full Astern, 35 Degrees Right Rudder Turning Maneuver (Run 2130)

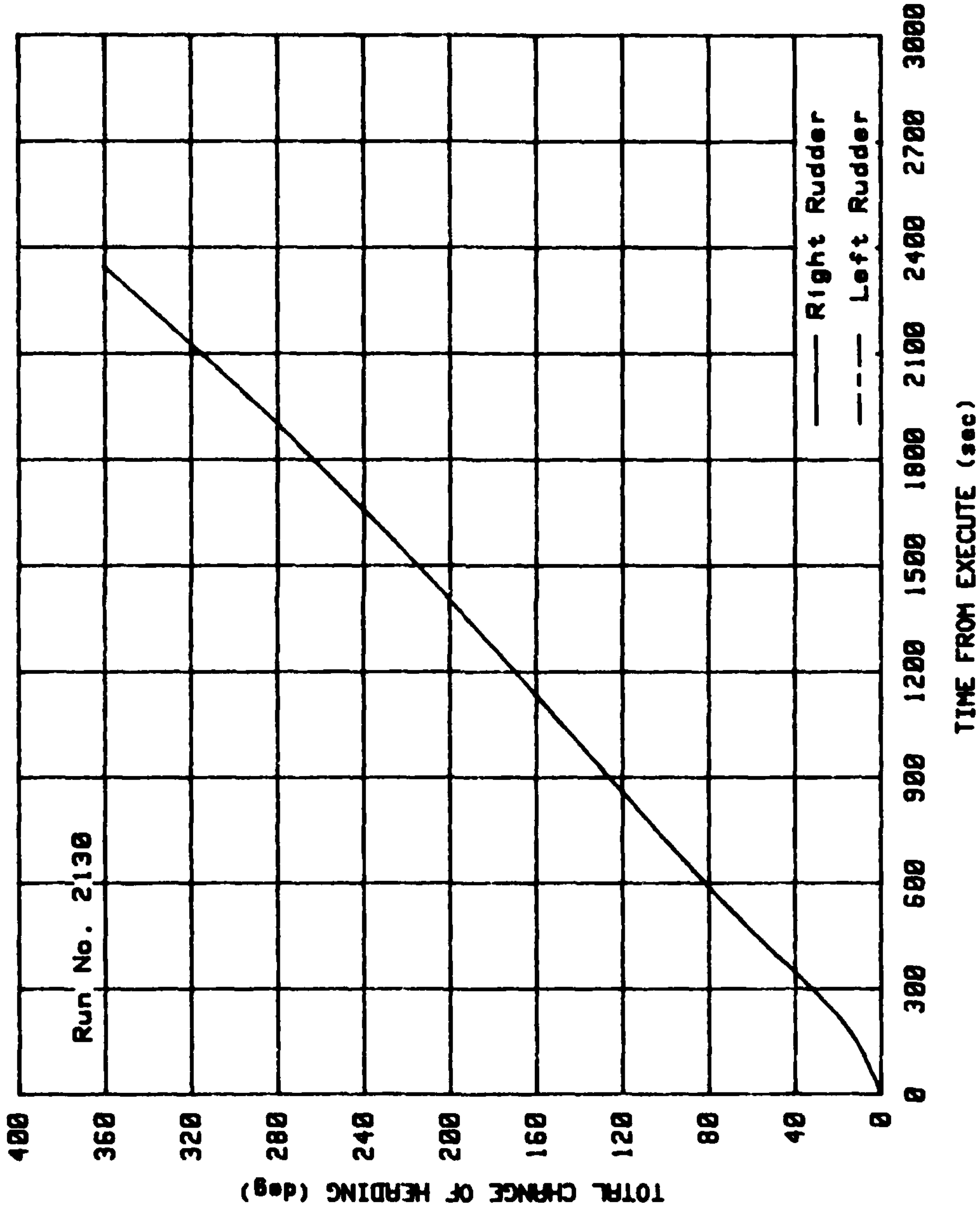

Figure 20 - Change of Heading Plot for Full Astern, 35 Degrees Right Rudder Turning Maneuver (Run 2130)

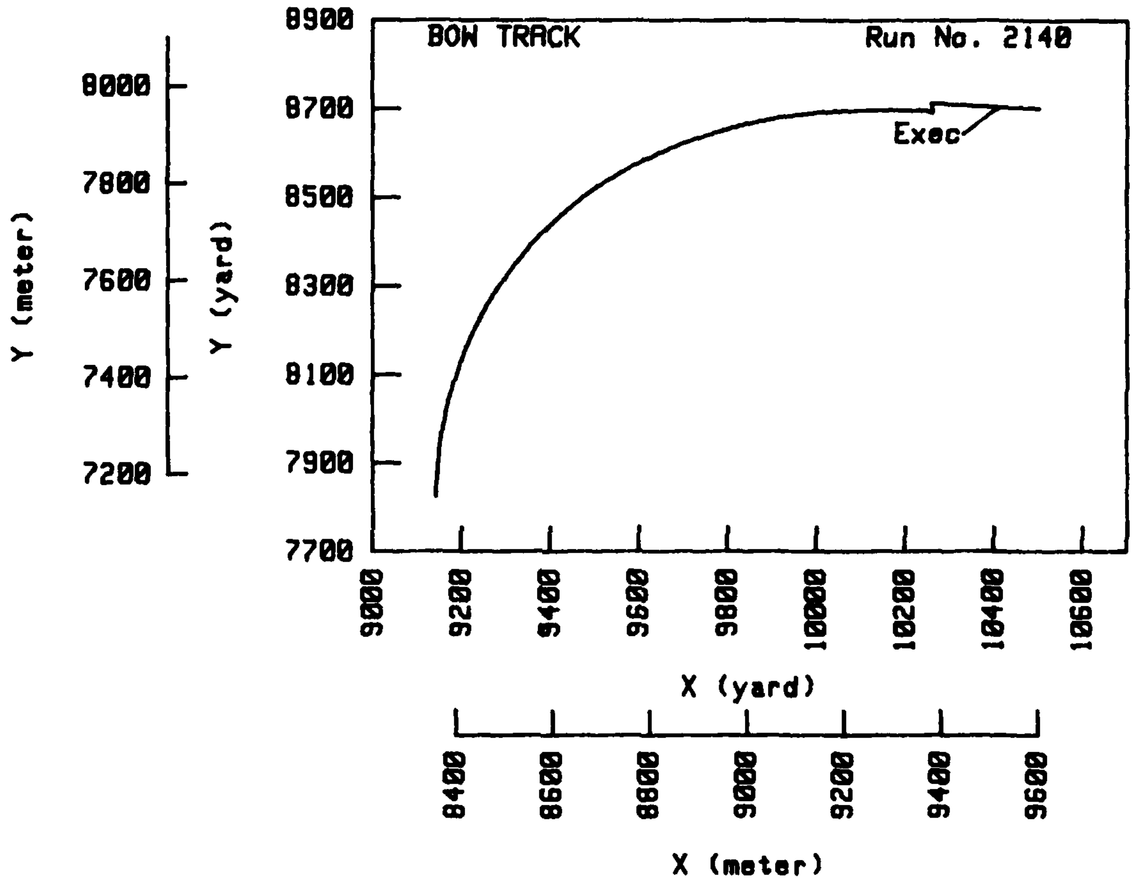

Figure 21 - Position Plot for Maximum Astern, 20 Degrees Right Rudder Turning Maneuver (Run 2140)

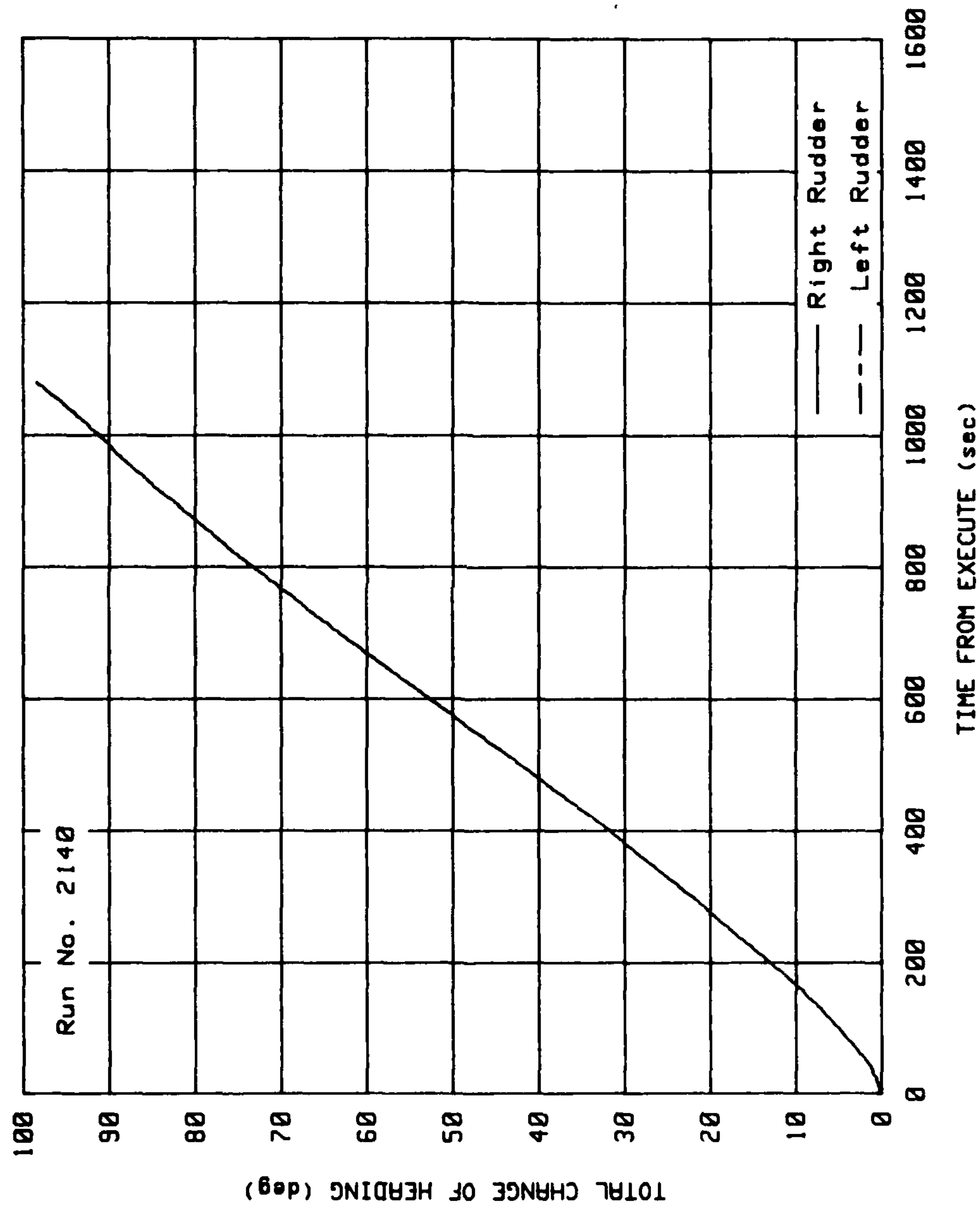

Figure 22 - Change of Heading Plot for Maximum Astern, 20 Degrees Right Rudder Turning Maneuver (Run 2140)

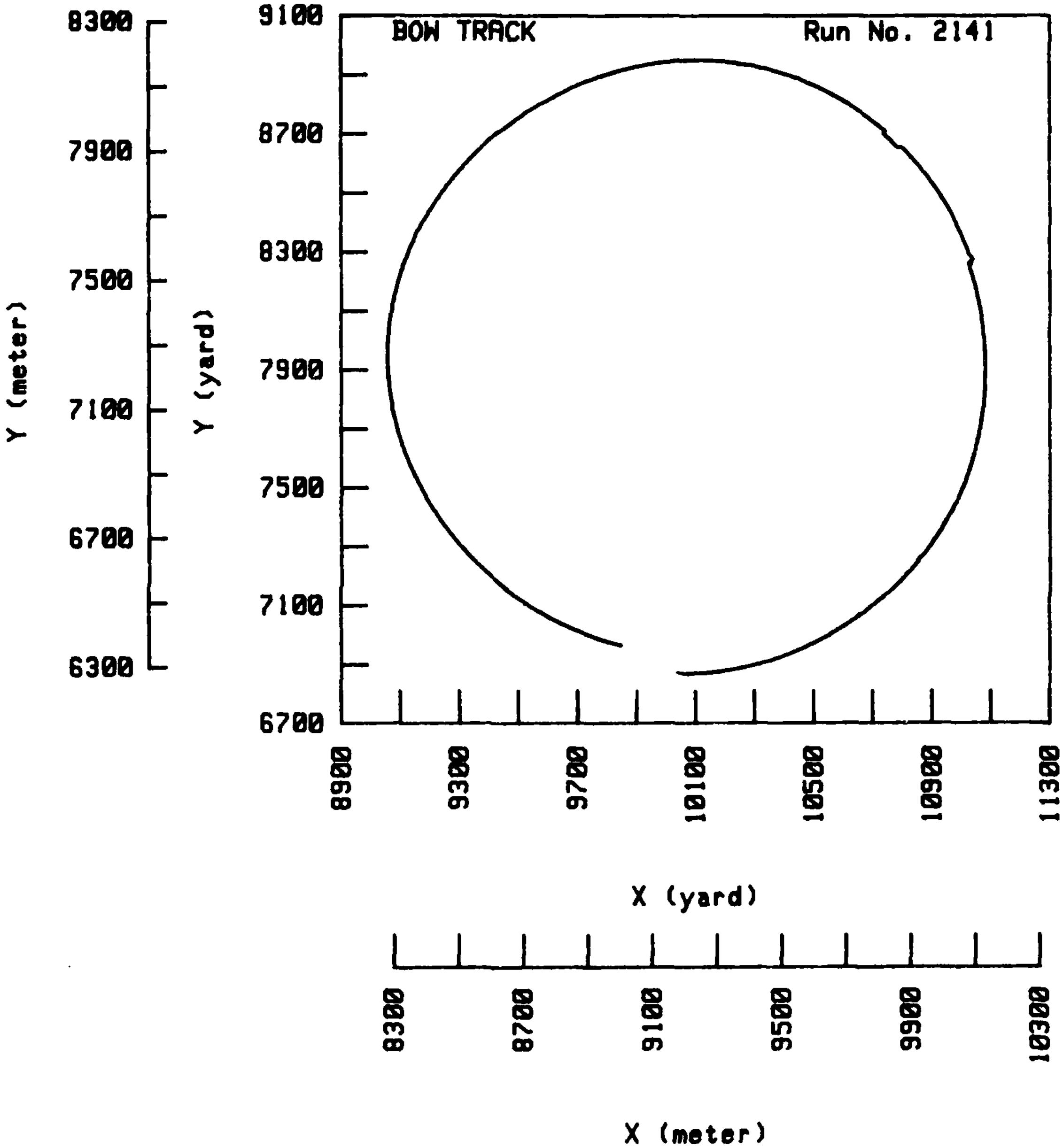

Figure 23 - Position Plot for Maximum Astern, 20 Degrees Right Rudder Turning Maneuver (Run 2141, Continuation of Run 2140)

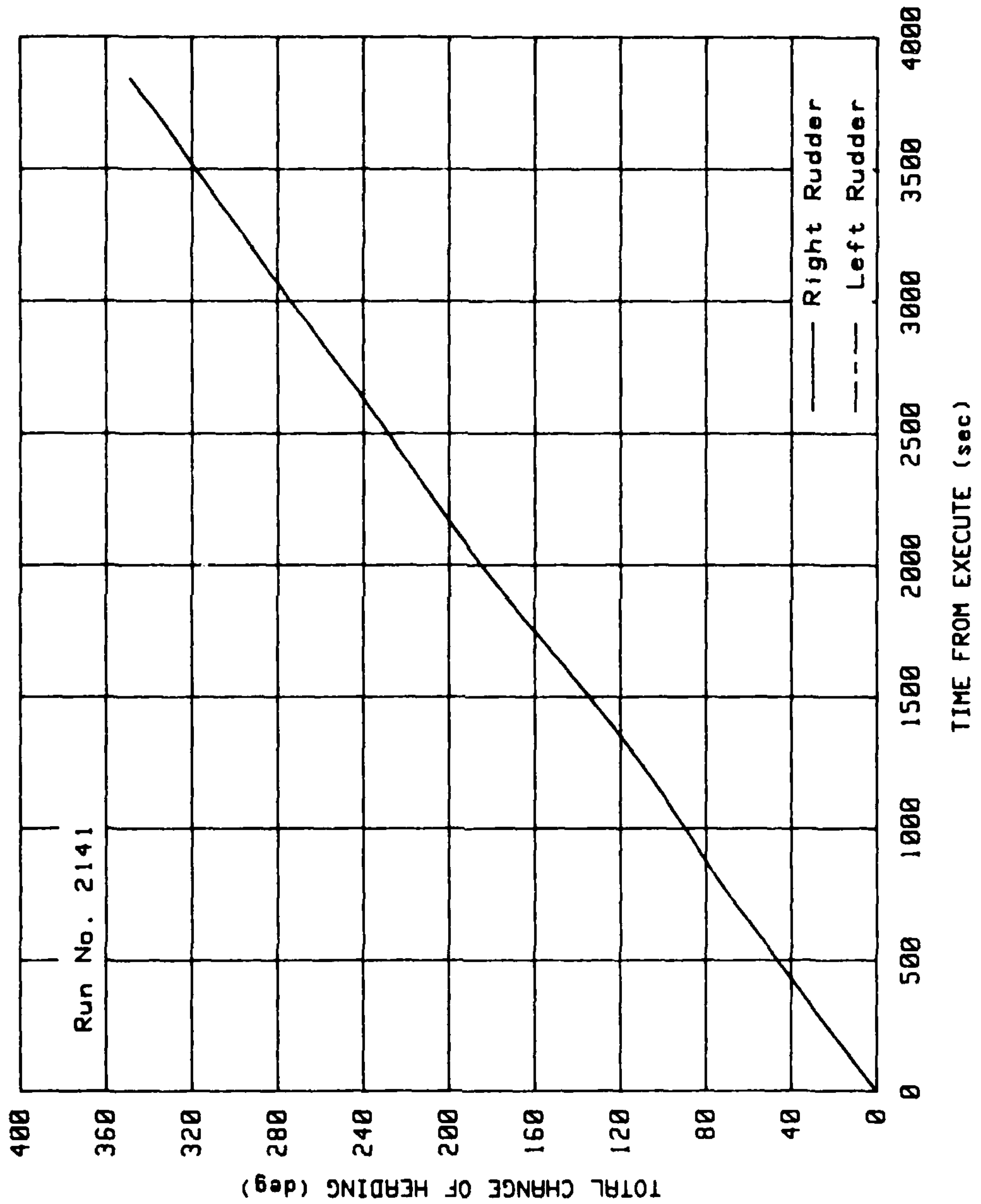

Figure 24 - Change of Heading Plot for Maximum Astern, 20 Degrees Right Rudder Turning Maneuver (Run 2141, Continuation of Run 2140)

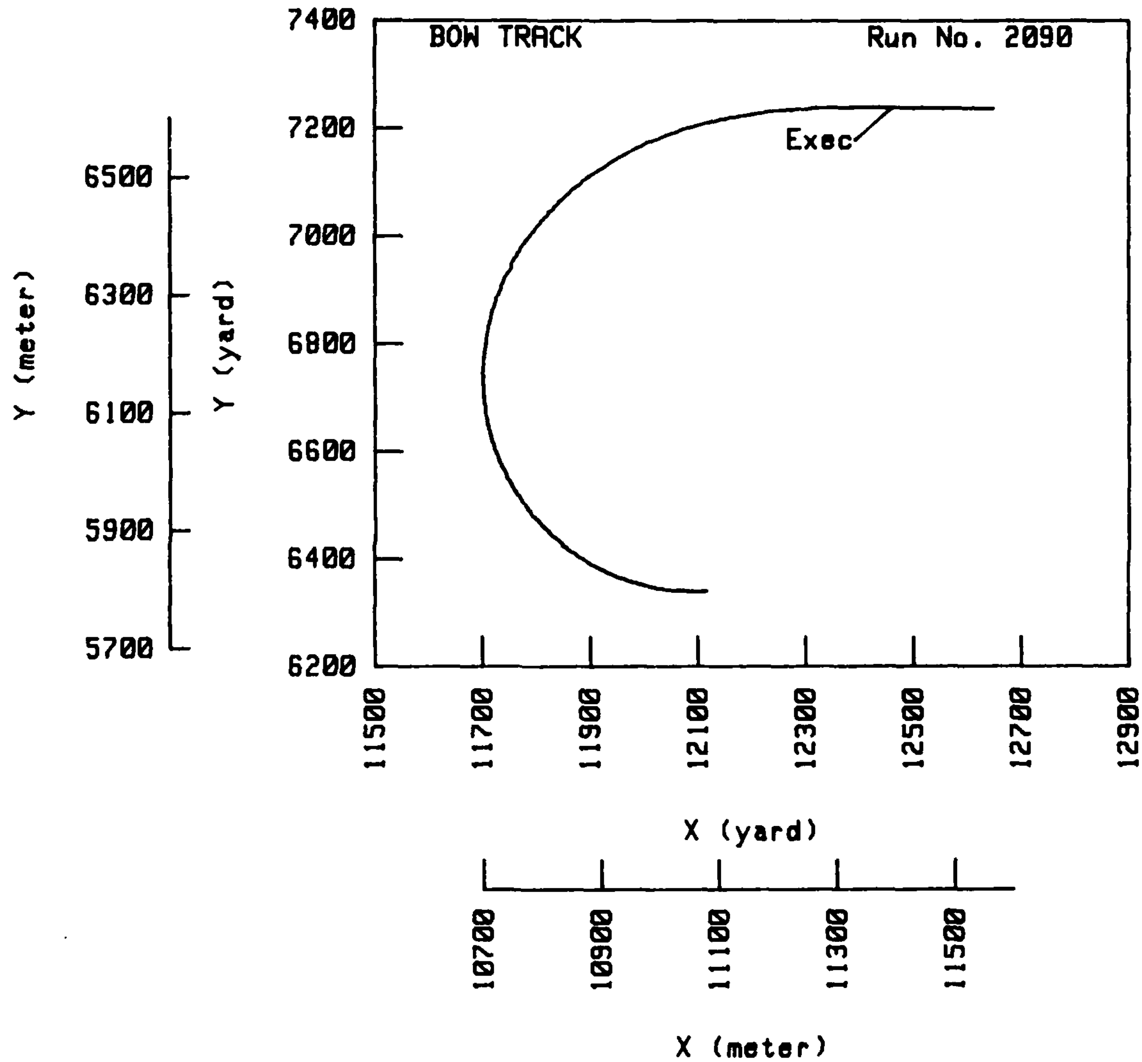

Figure 25 - Position Plot for Full Ahead to Half Ahead, 35 Degrees Left Rudder Turning Maneuver (Run 2090)

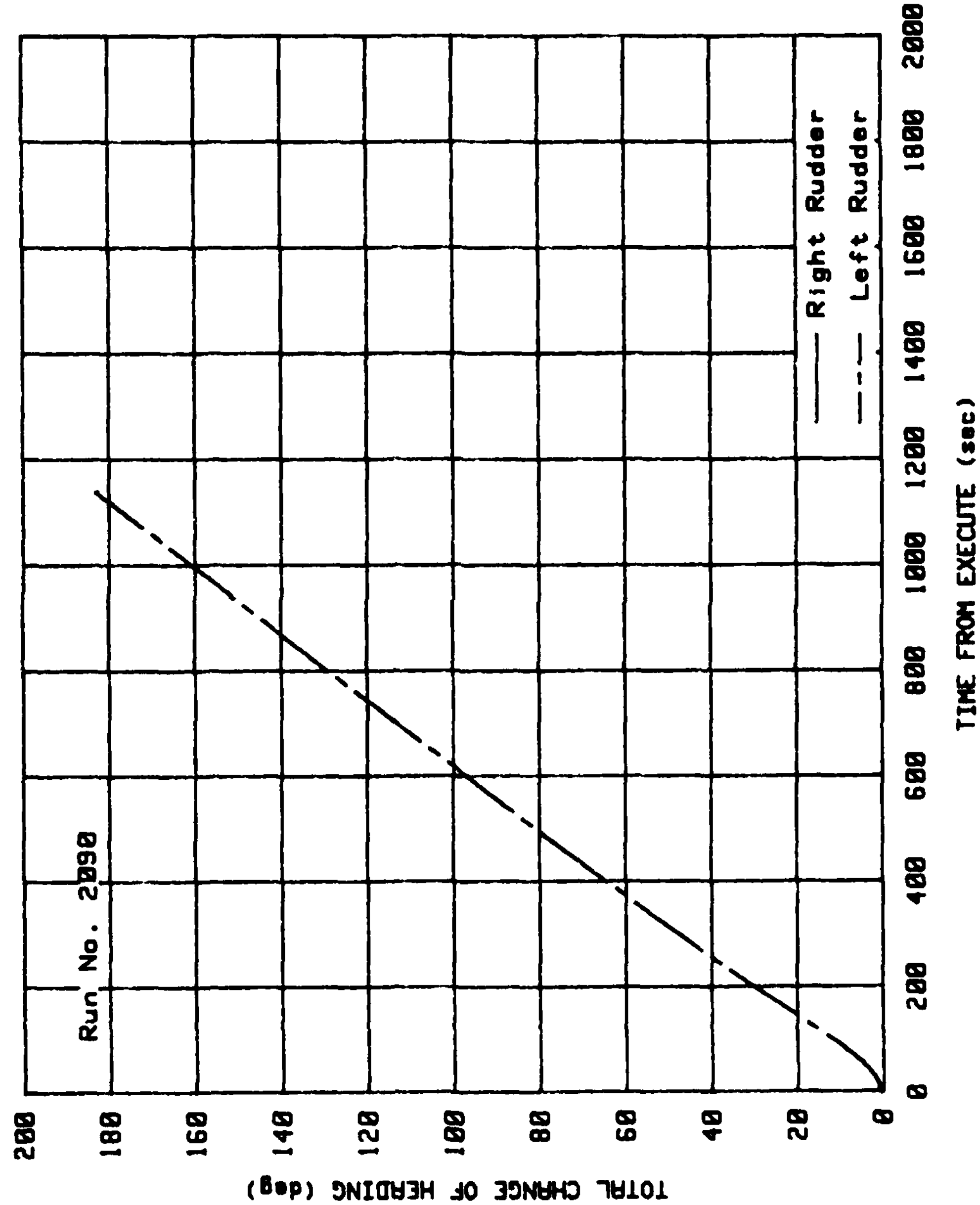

Figure 26 - Change of Heading Plot for Full Ahead to Half Ahead, 35 Degrees Left Rudder Turning Maneuver (Run 2090)

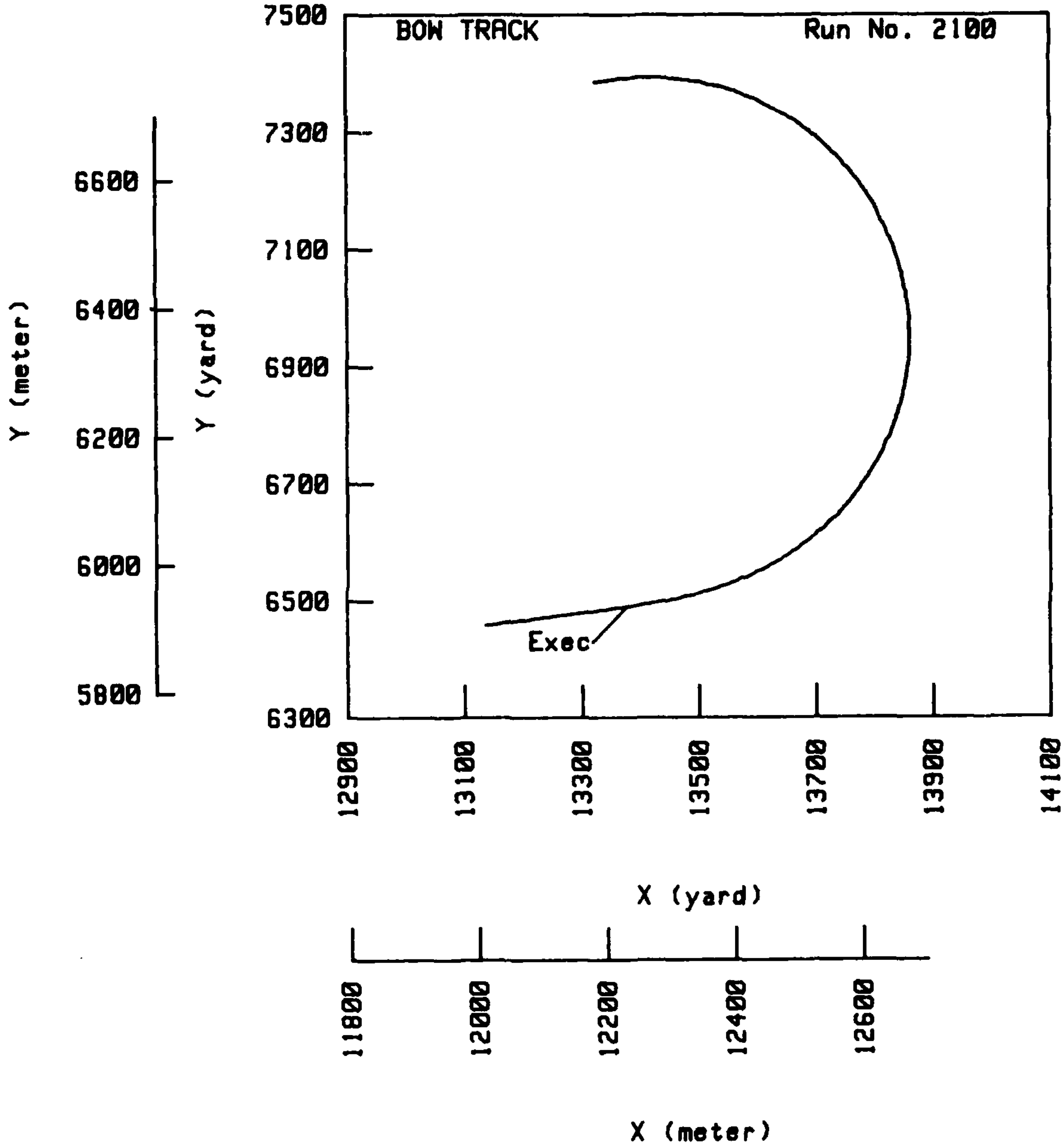

Figure 27 - Position Plot for Half Ahead to Full Ahead, 35 Degrees Left Rudder Turning Maneuver (Run 2100)

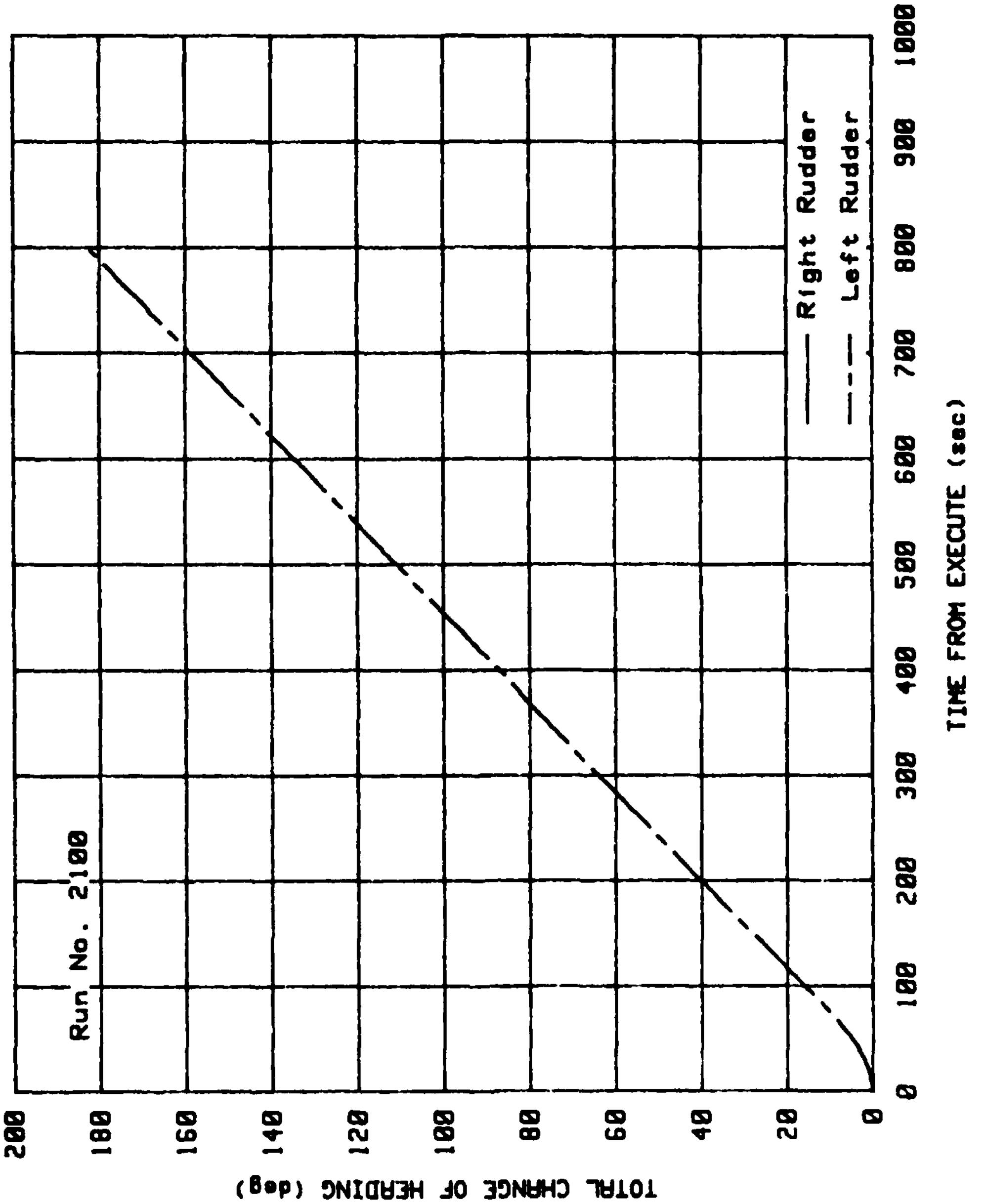

Figure 28 - Change of Heading Plot for Half Ahead to Full Ahead, 35 Degrees Left Rudder Turning Maneuver (Run 2100)

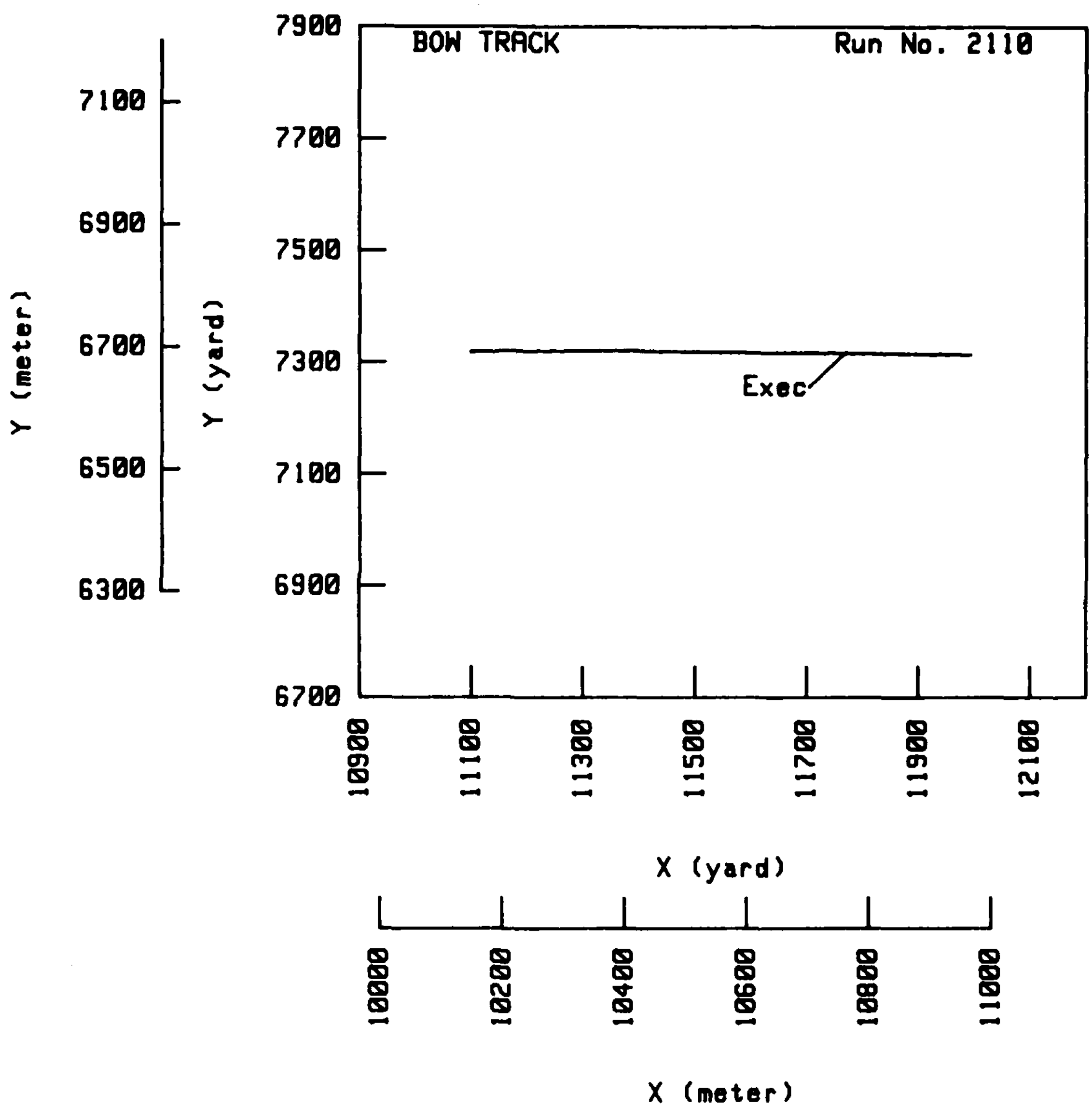

Figure 29 - Position Plot for Full Ahead to All Stop, 35 Degrees Right Rudder Turning Maneuver (Run 2110)

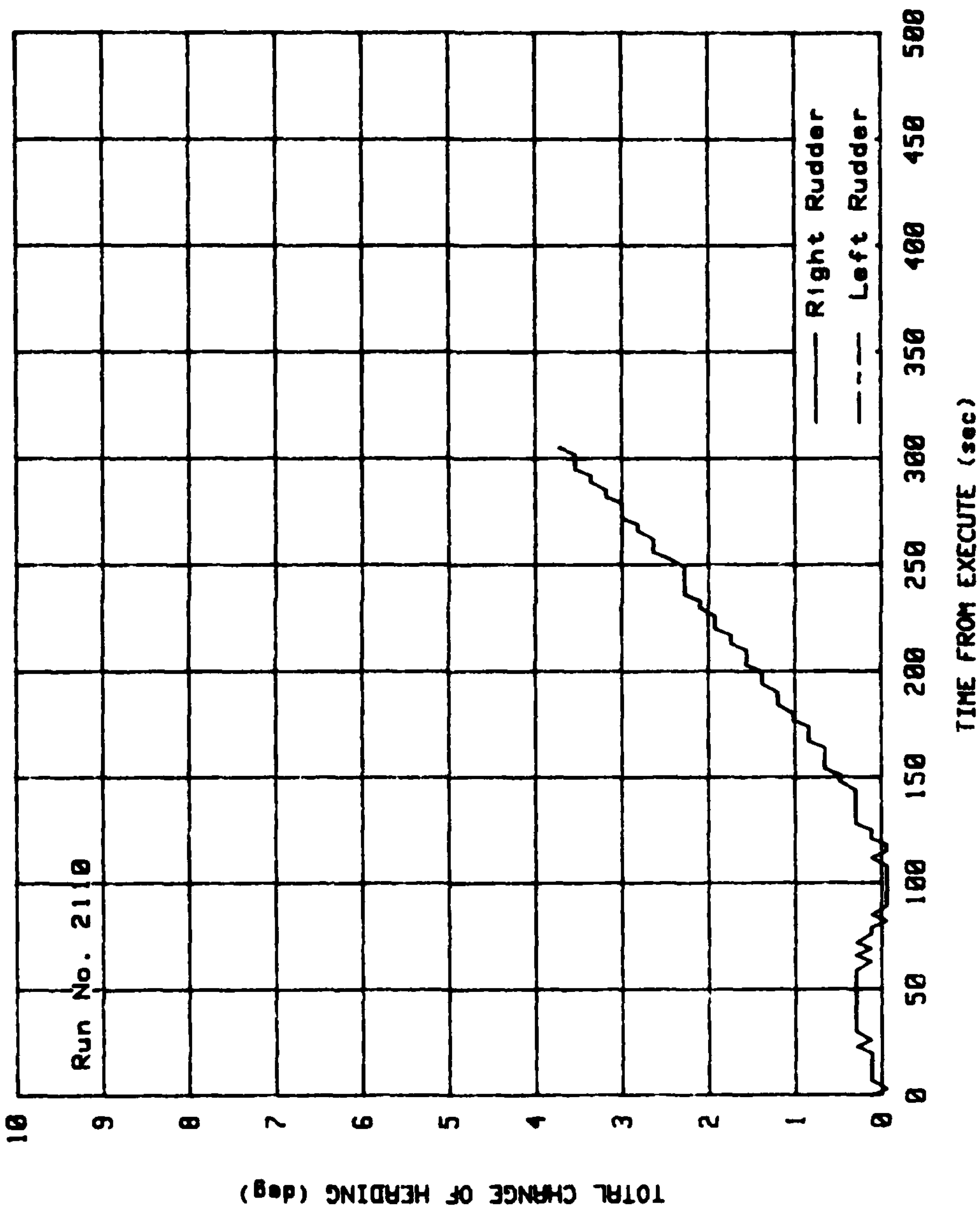

Figure 30 - Change of Heading Plot for Full Ahead to All Stop,
35 Degrees Right Rudder Turning Maneuver (Run 2110)

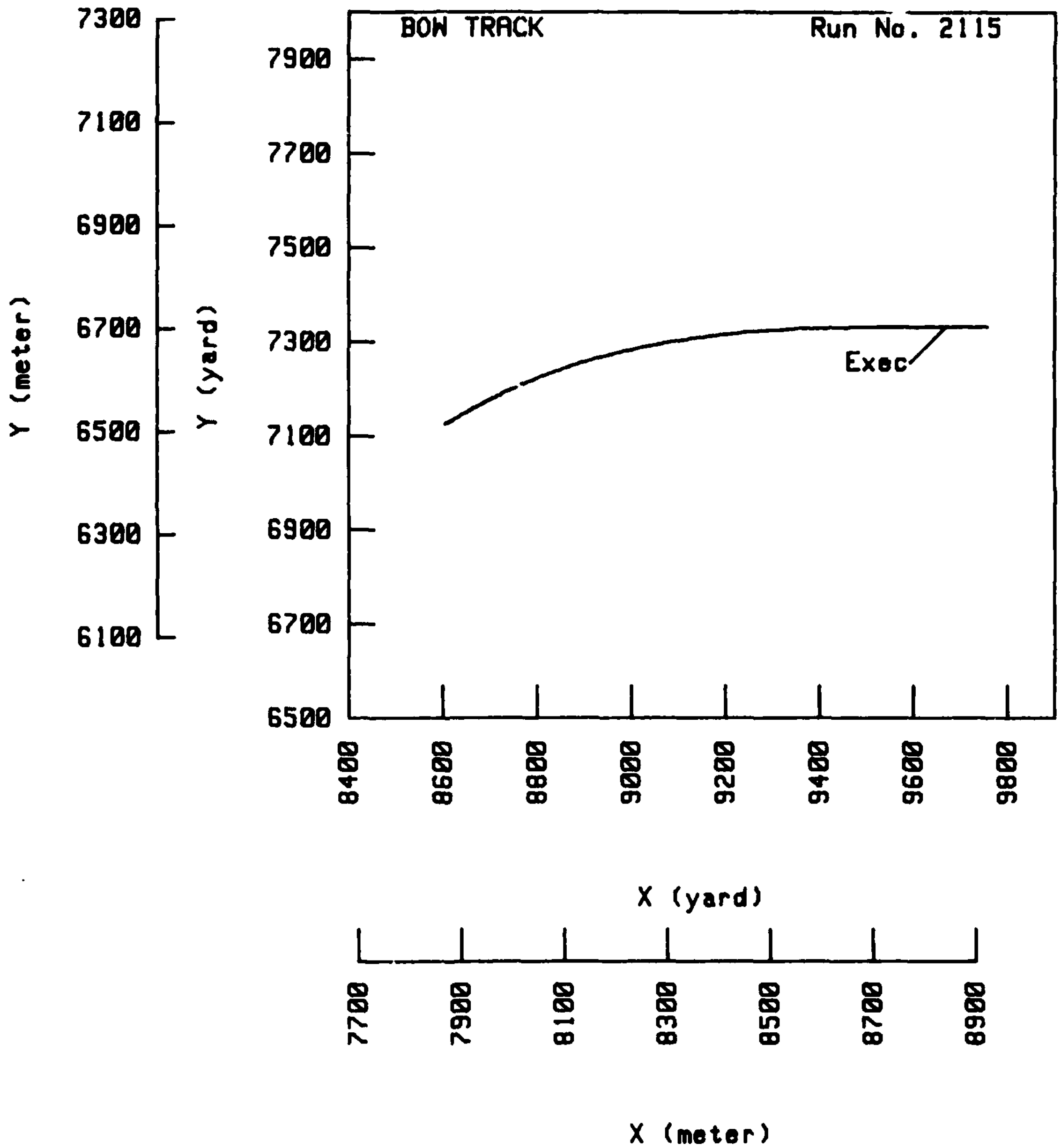

Figure 31 - Position Plot for Full Ahead to All Stop, 35 Degrees Left Rudder Turning Maneuver (Run 2115)

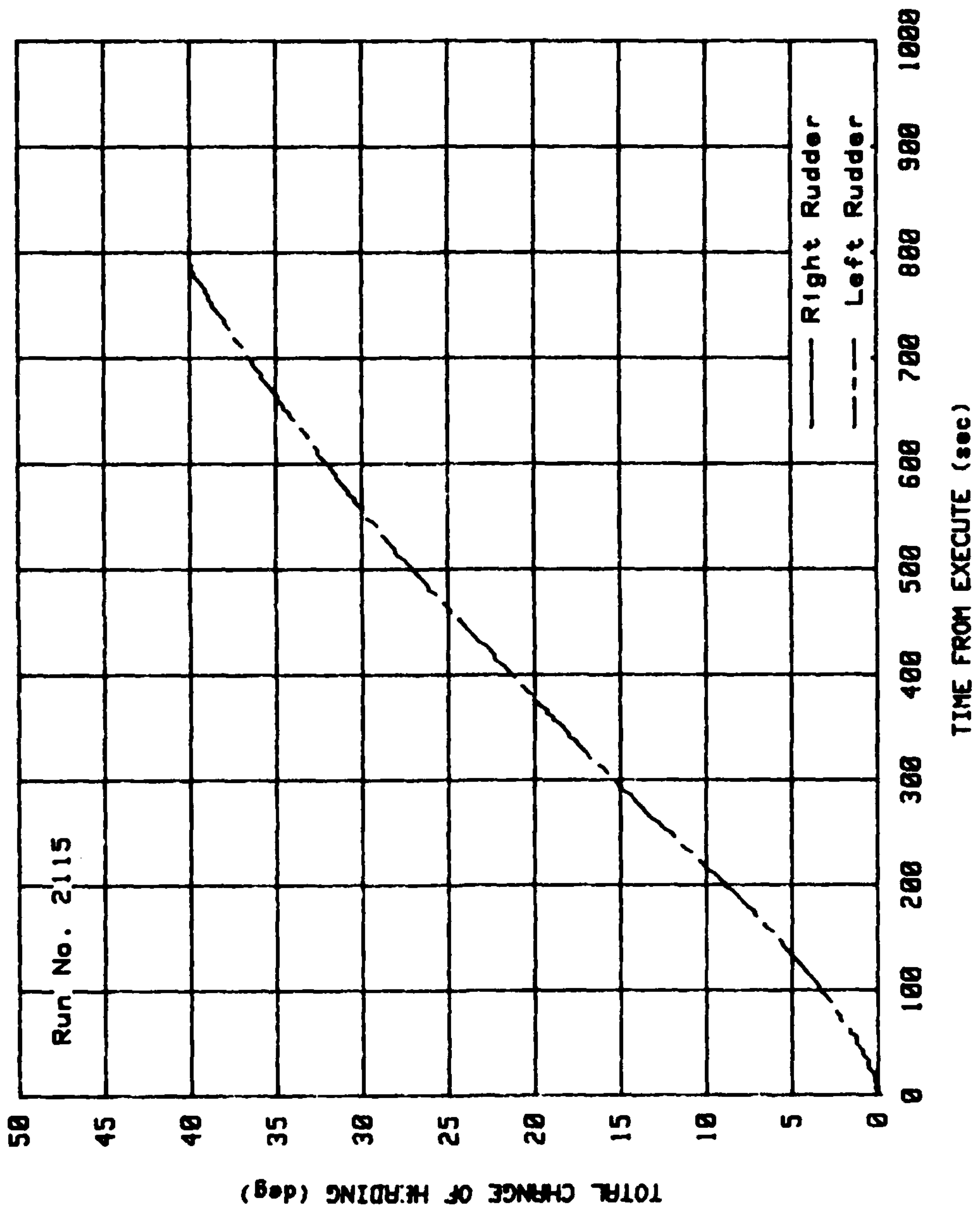

Figure 32 - Change of Heading Plot for Full Ahead to All Stop, 35 Degrees Left Rudder Turning Maneuver (Run 2115)

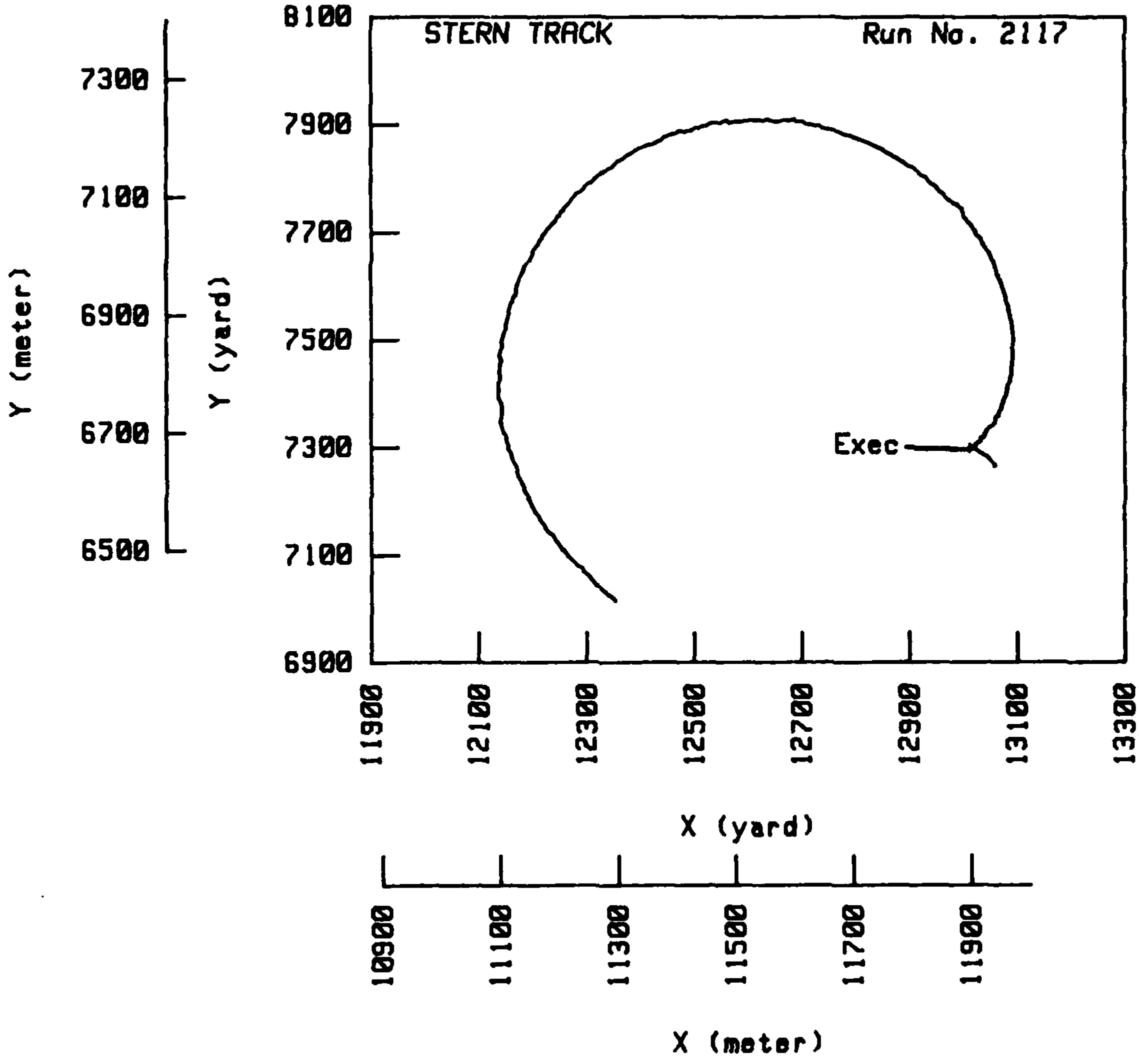

Figure 33 - Position Plot for All Stop to Full Ahead, 35 Degrees Left Rudder Turning Maneuver (Run 2117)

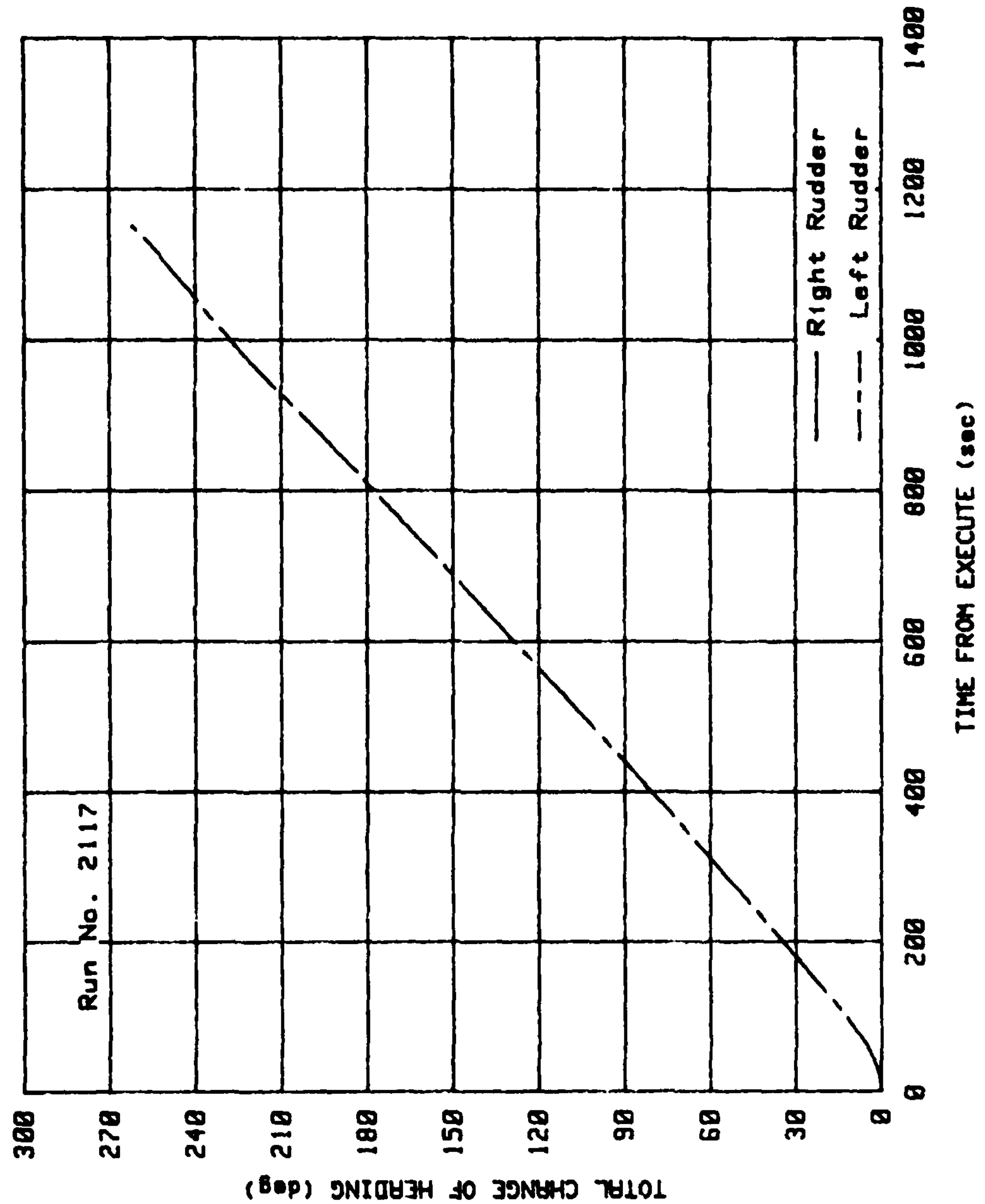

Figure 34 - Change of Heading Plot for All Stop to Full Ahead, 35 Degrees Left Rudder Turning Maneuver (Run 2117)

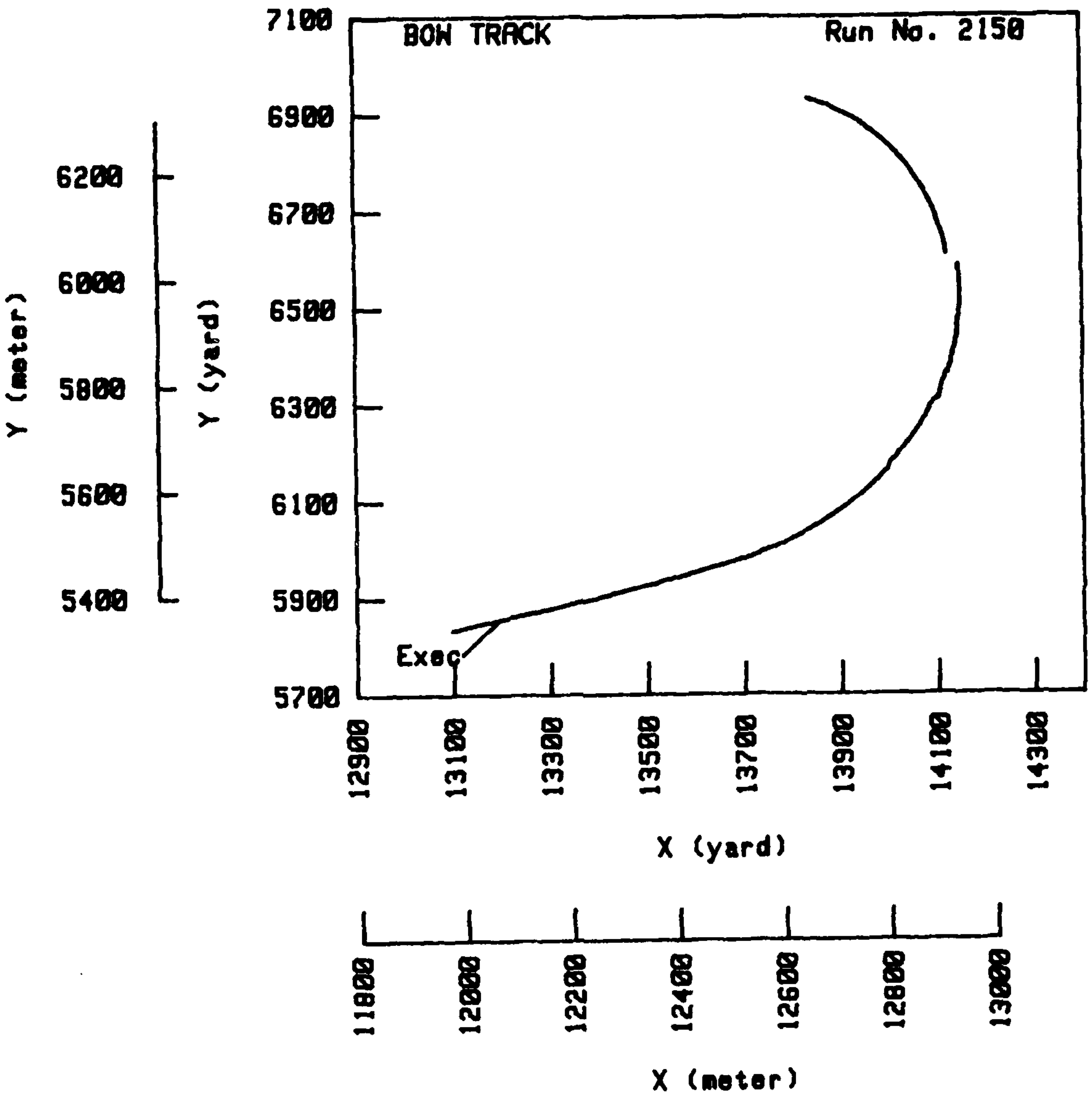

Figure 35 - Position Plot for Full Astern to Half Astern, 35 Degrees Right Rudder Turning Maneuver (Run 2150)

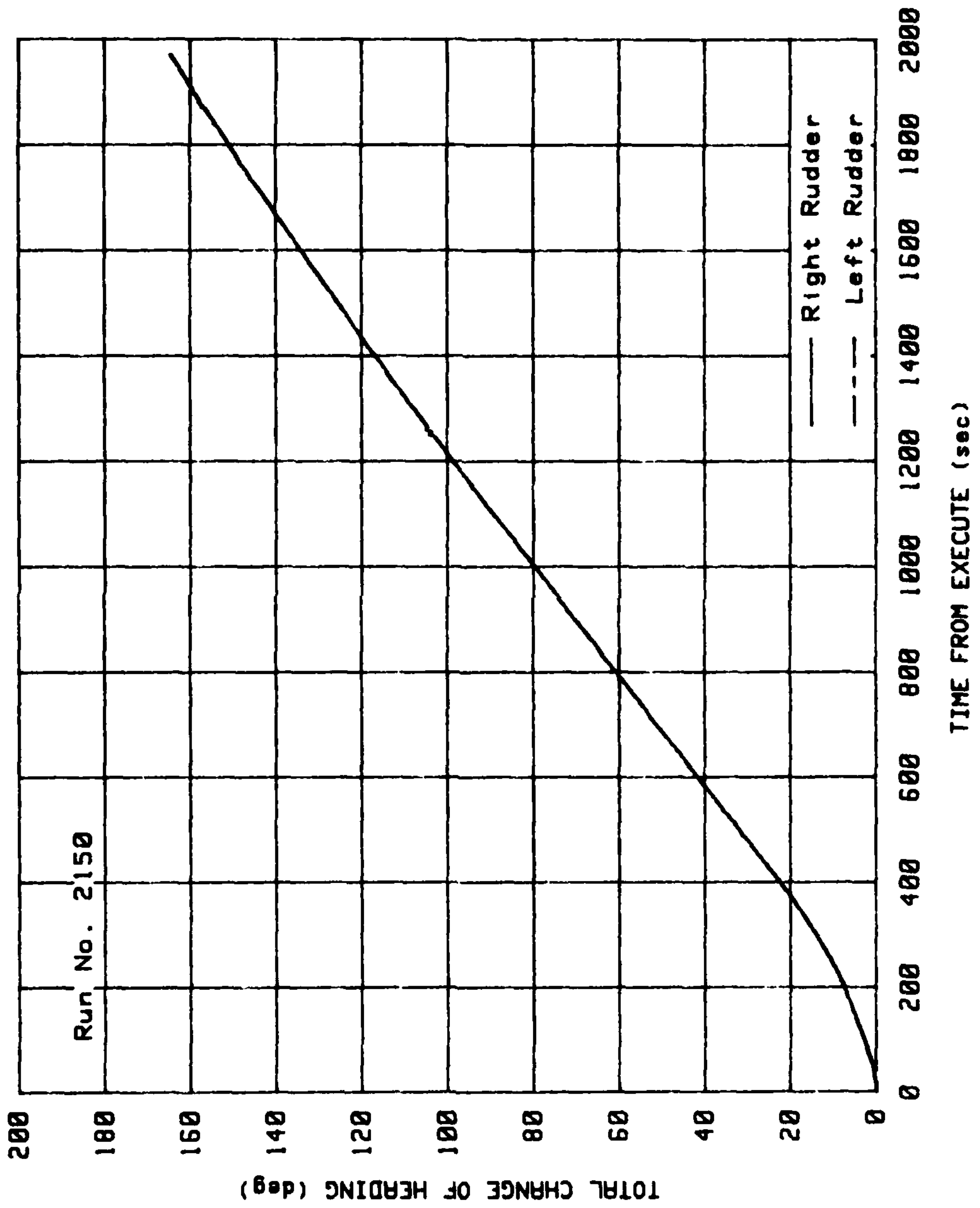

Figure 36 - Change of Heading Plot for Full Astern to Half Astern, 35 Degrees Right Rudder Turning Maneuver (Run 2150)

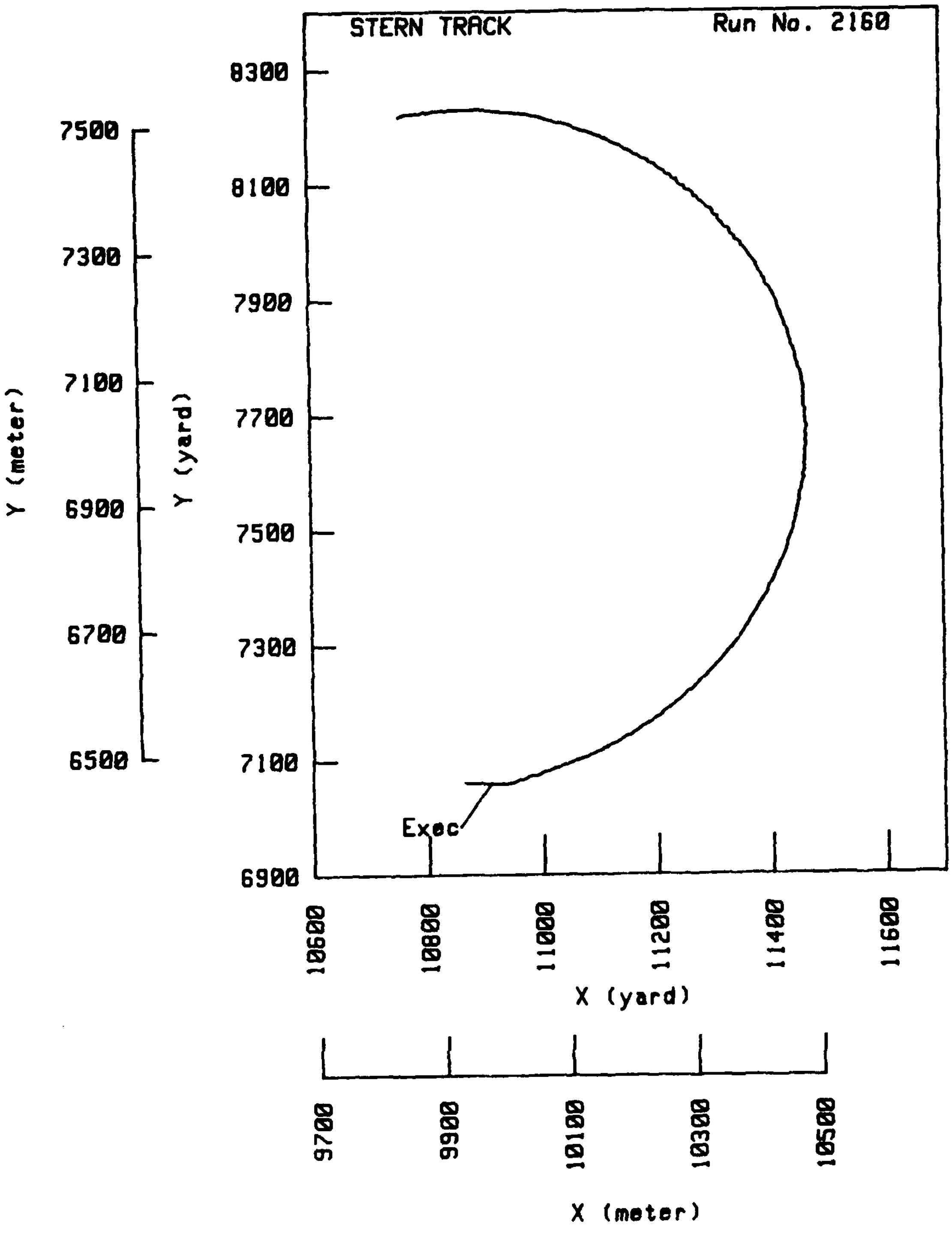

Figure 37 - Position Plot for Half Astern to Full Astern, 35 Degrees Right Rudder Turning Maneuver (Run 2160)

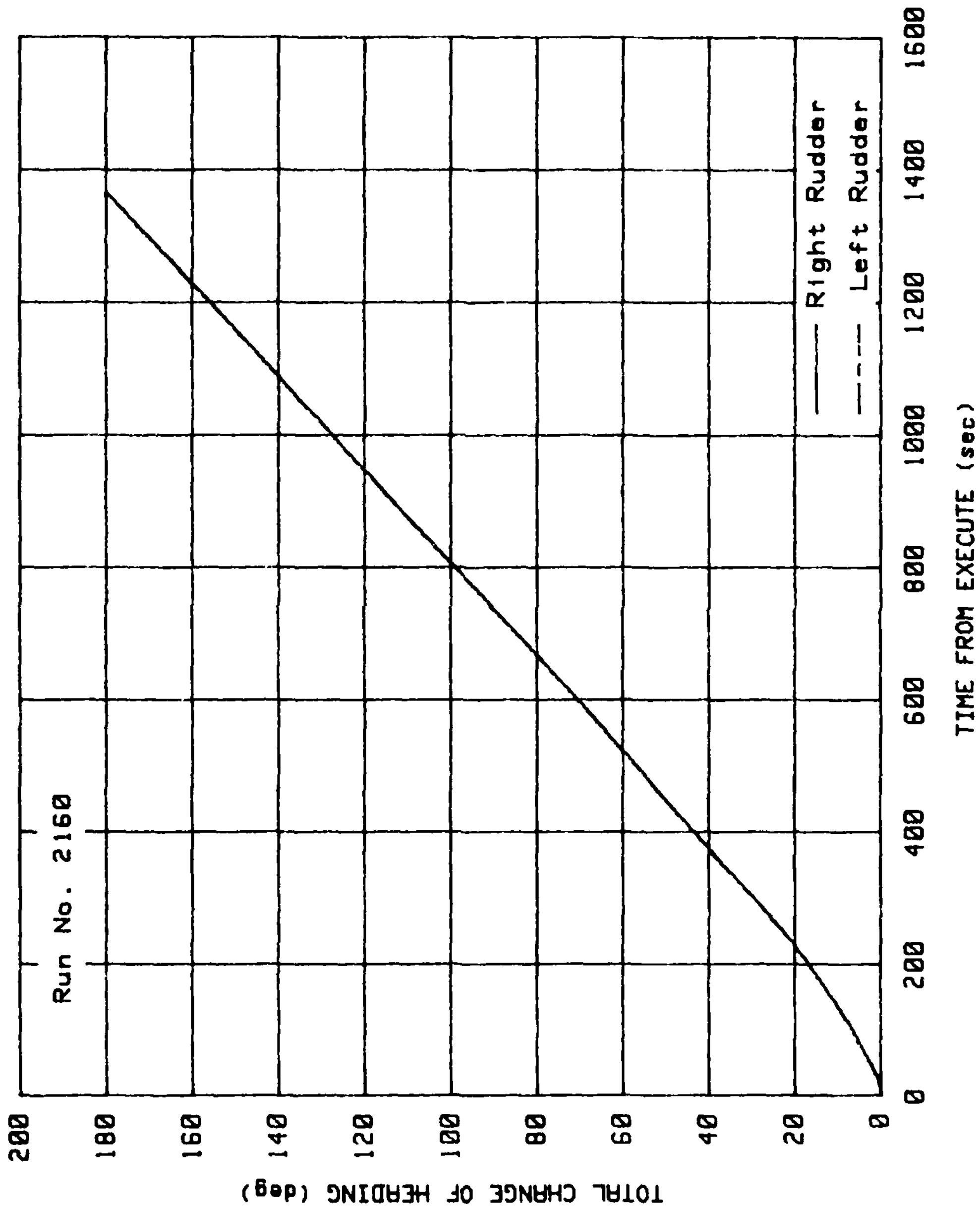

Figure 38 - Change of Heading Plot for Half Astern to Full Astern, 35 Degrees Right Rudder Turning Maneuver (Run 2160)

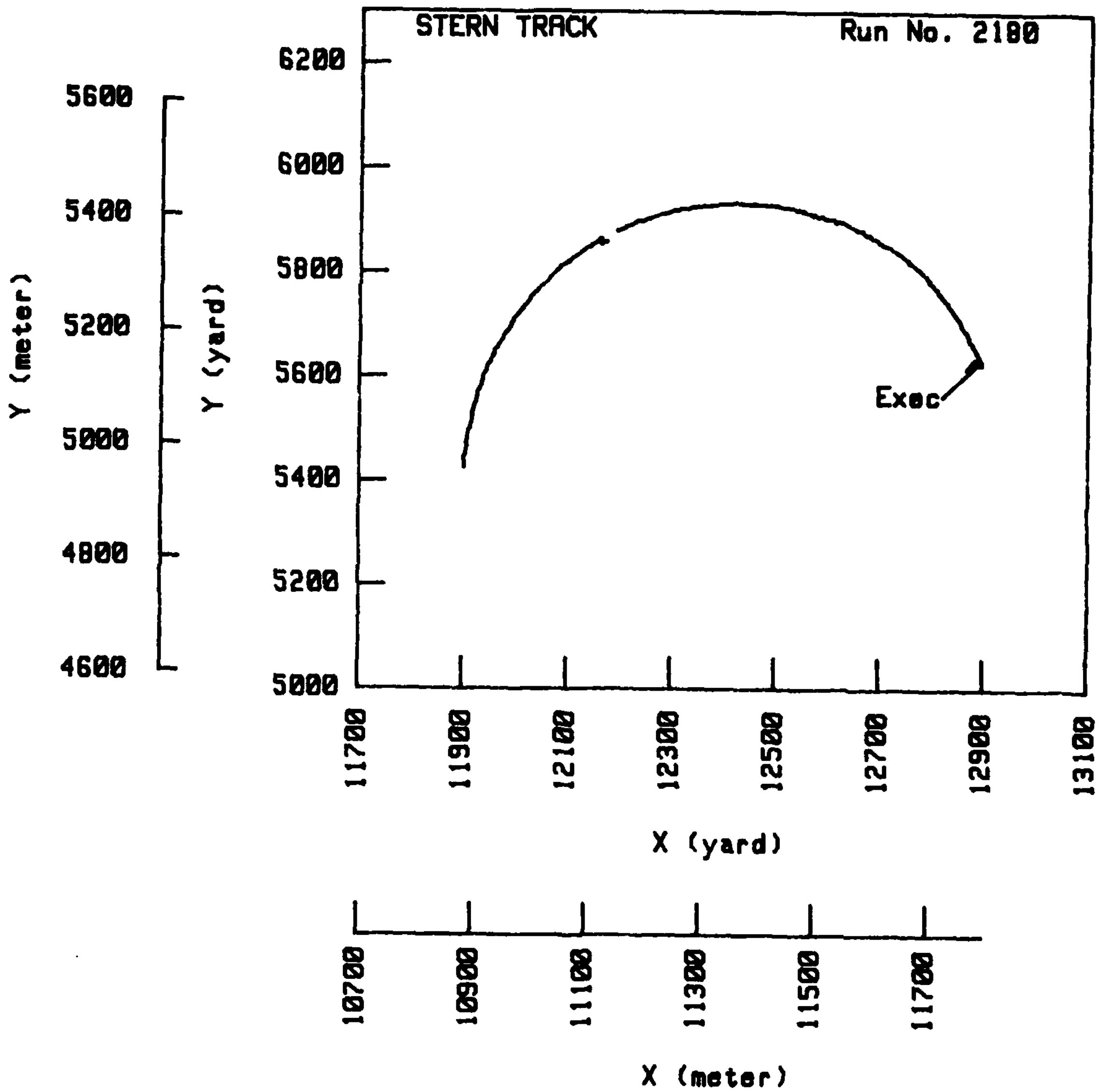

Figure 39 - Position Plot for All Stop to Full Astern, 35 Degrees Right Rudder Turning Maneuver (Run 2180)

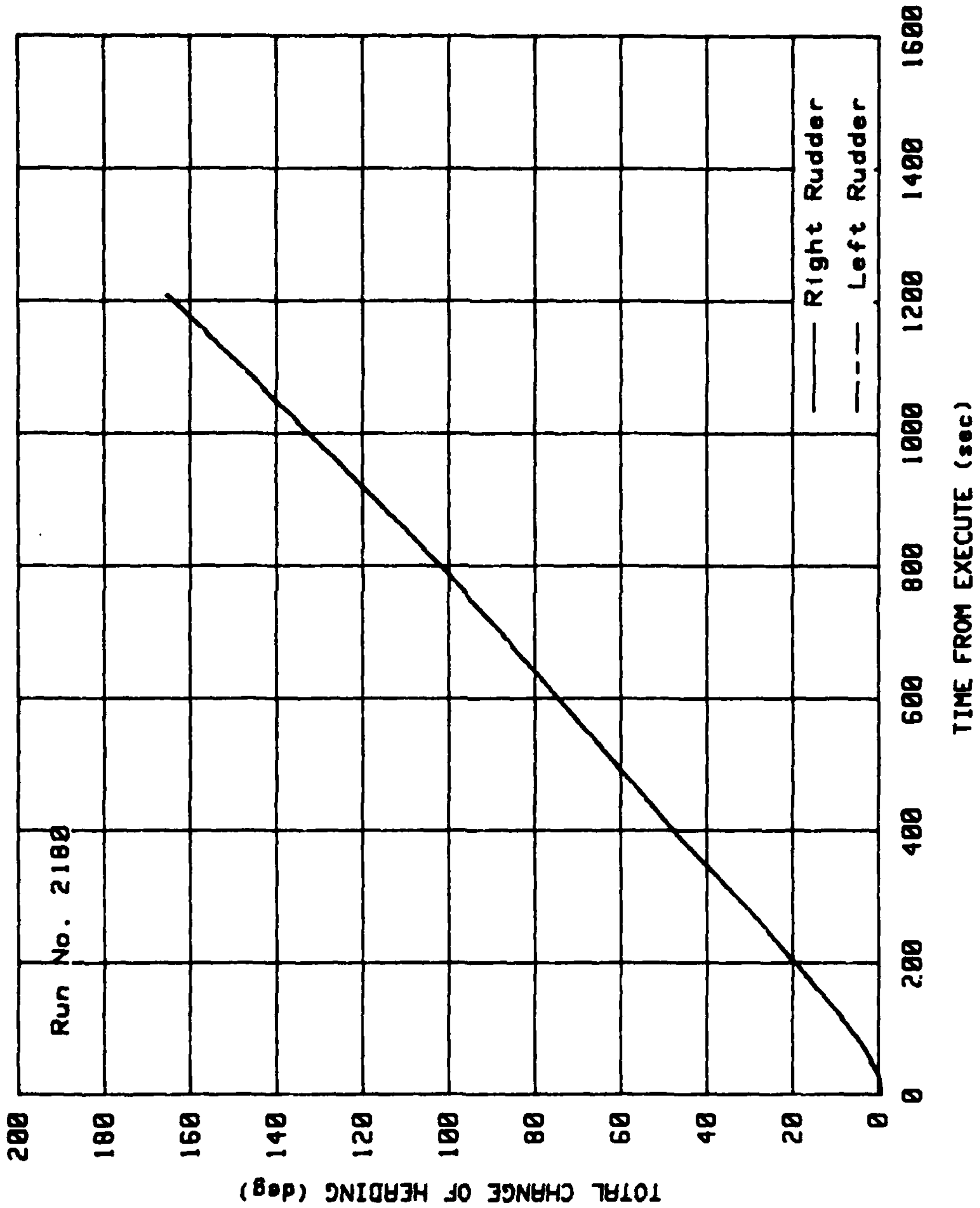

Figure 40 - Change of Heading Plot for All Stop to Full Astern, 35 Degrees Right Rudder Turning Maneuver (Run 2180)

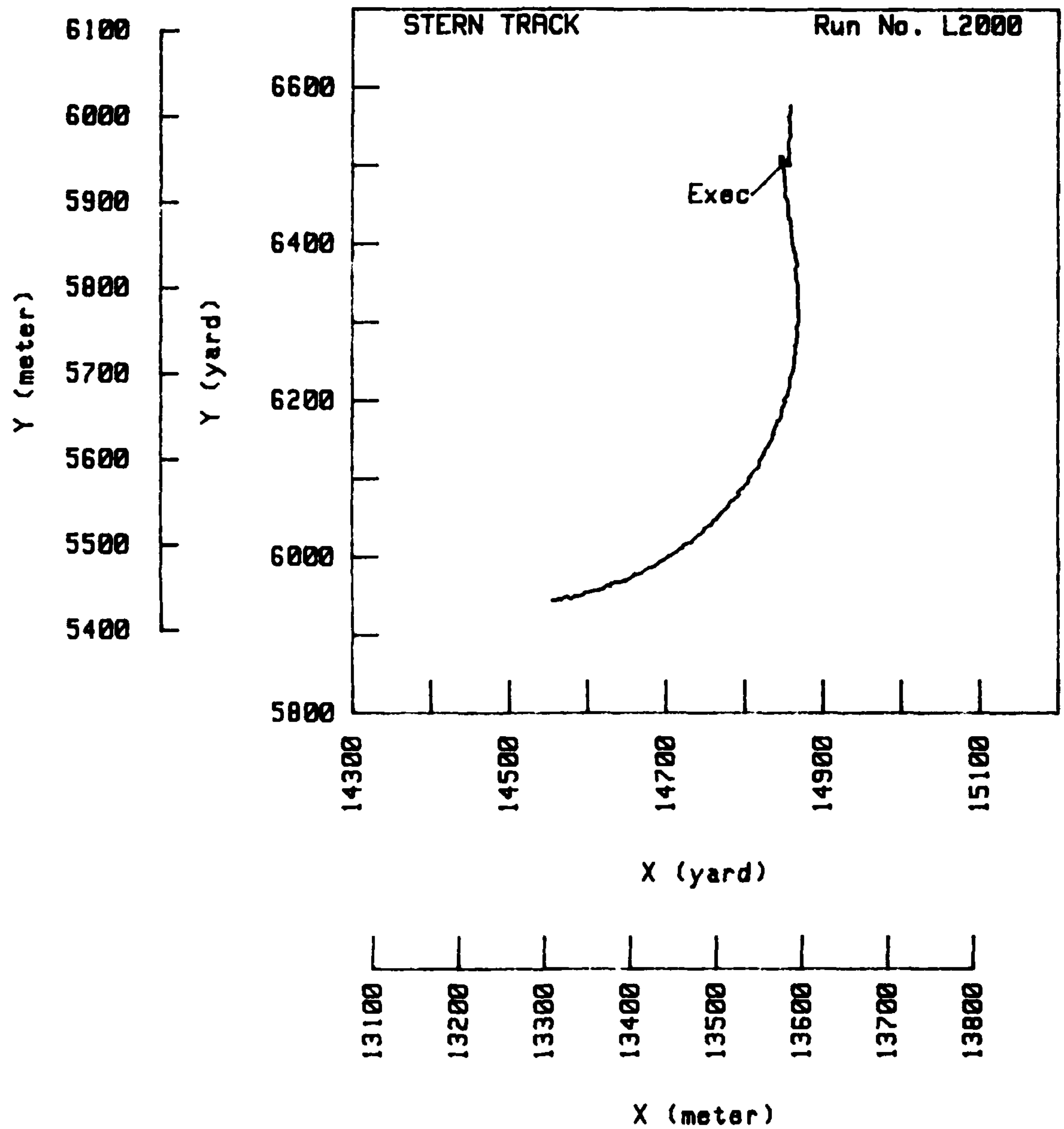

Figure 41 - Position Plot for Half Ahead, 35 Degrees Right Rudder Turning Maneuver (Run L2000)

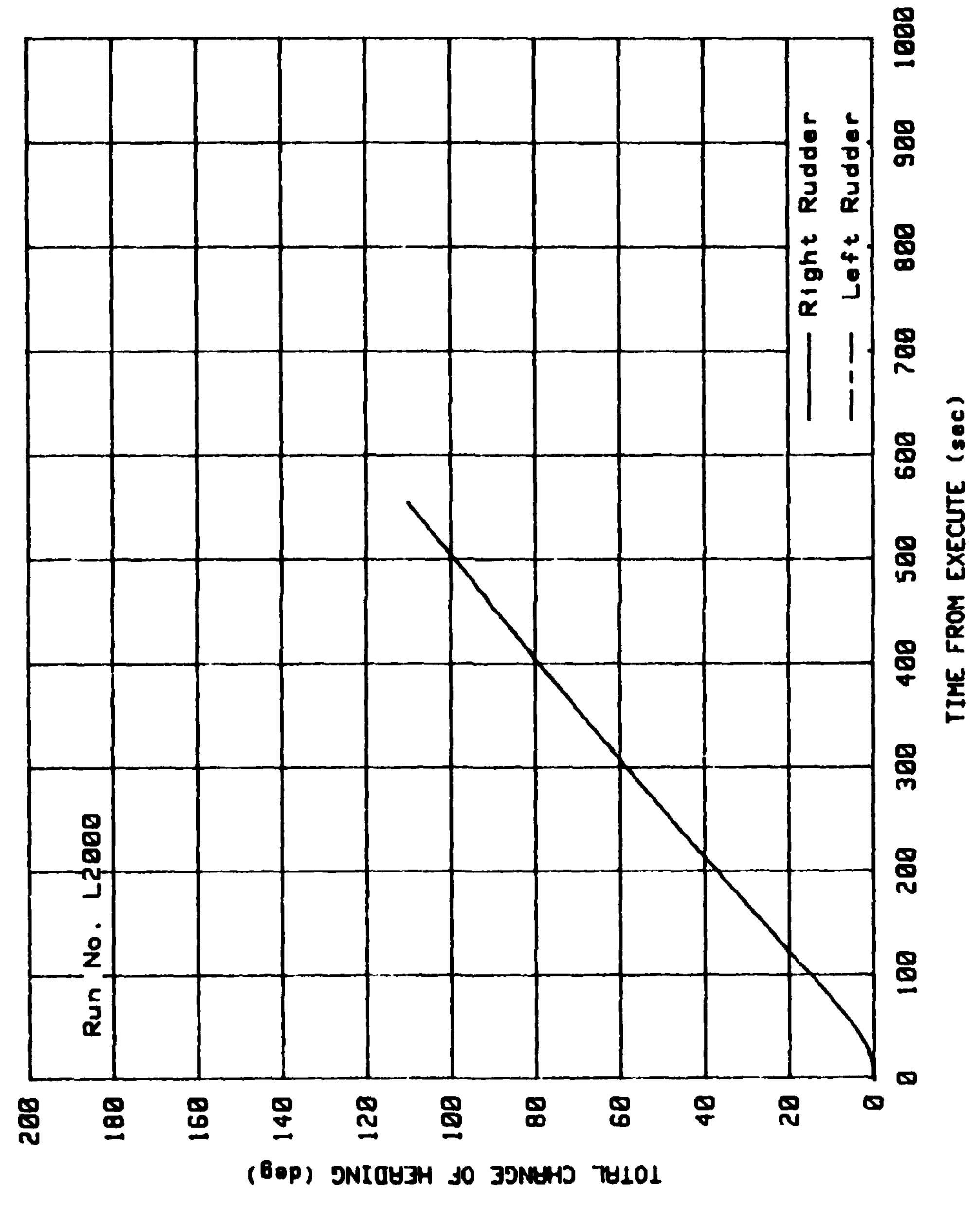

Figure 42 - Change of Heading Plot for Half Ahead, 35 Degrees Right Rudder Turning Maneuver (Run L2000)

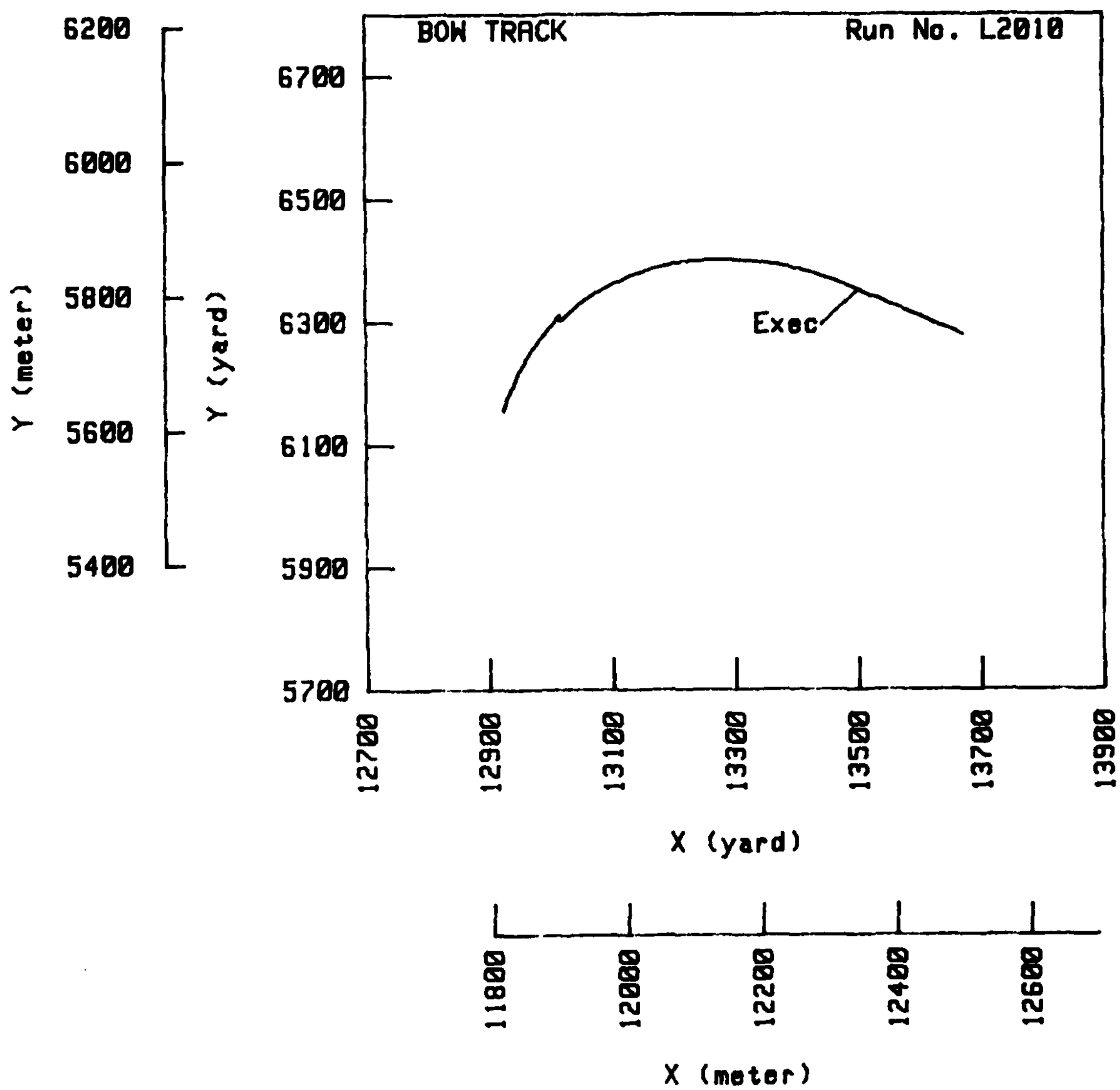

Figure 43 - Position Plot for Full Ahead, 35 Degrees Left Rudder Turning Maneuver (Run L2010)

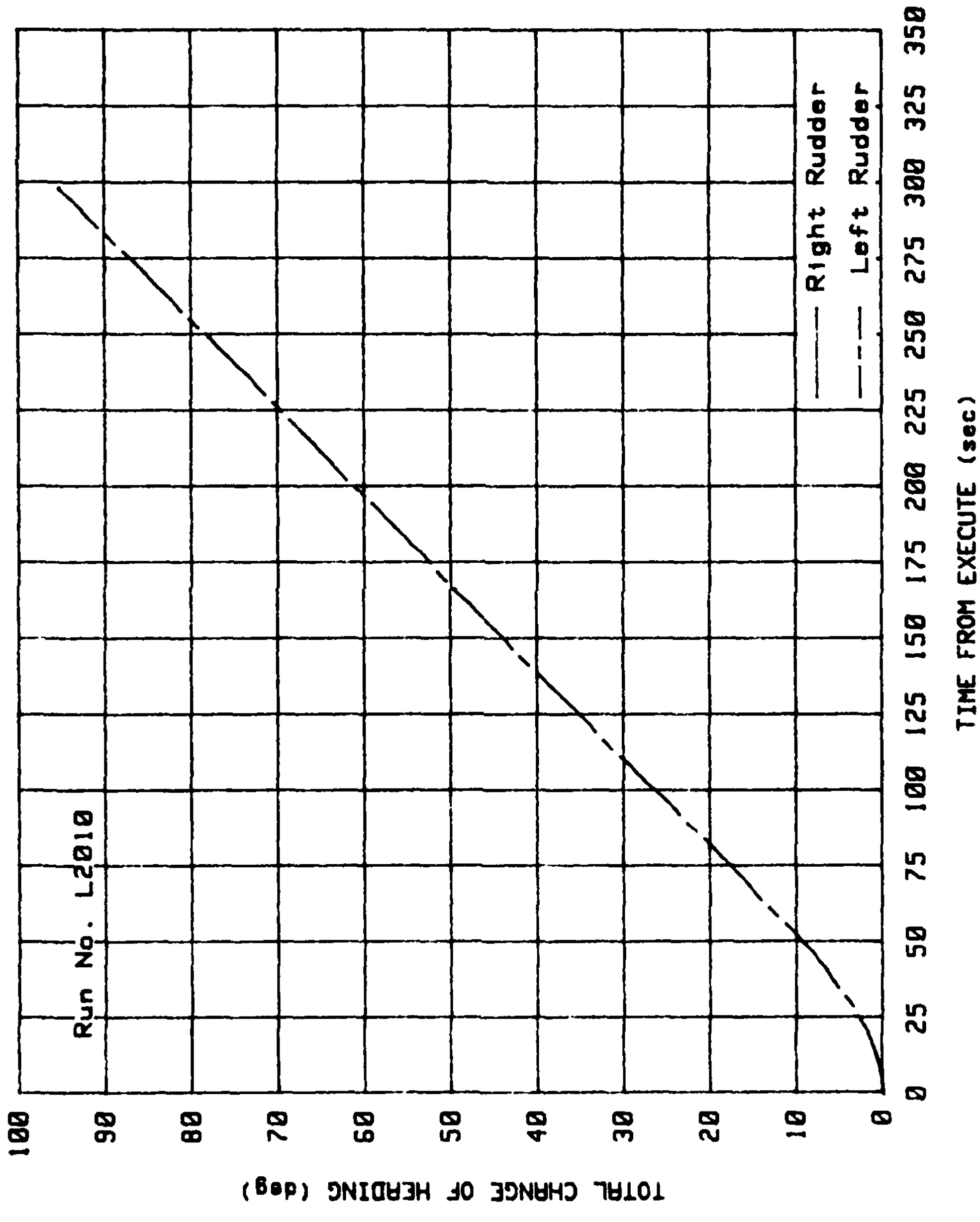

Figure 44 - Change of Heading Plot for Full Ahead, 35 Degrees Left Rudder Turning Maneuver (Run L2010)

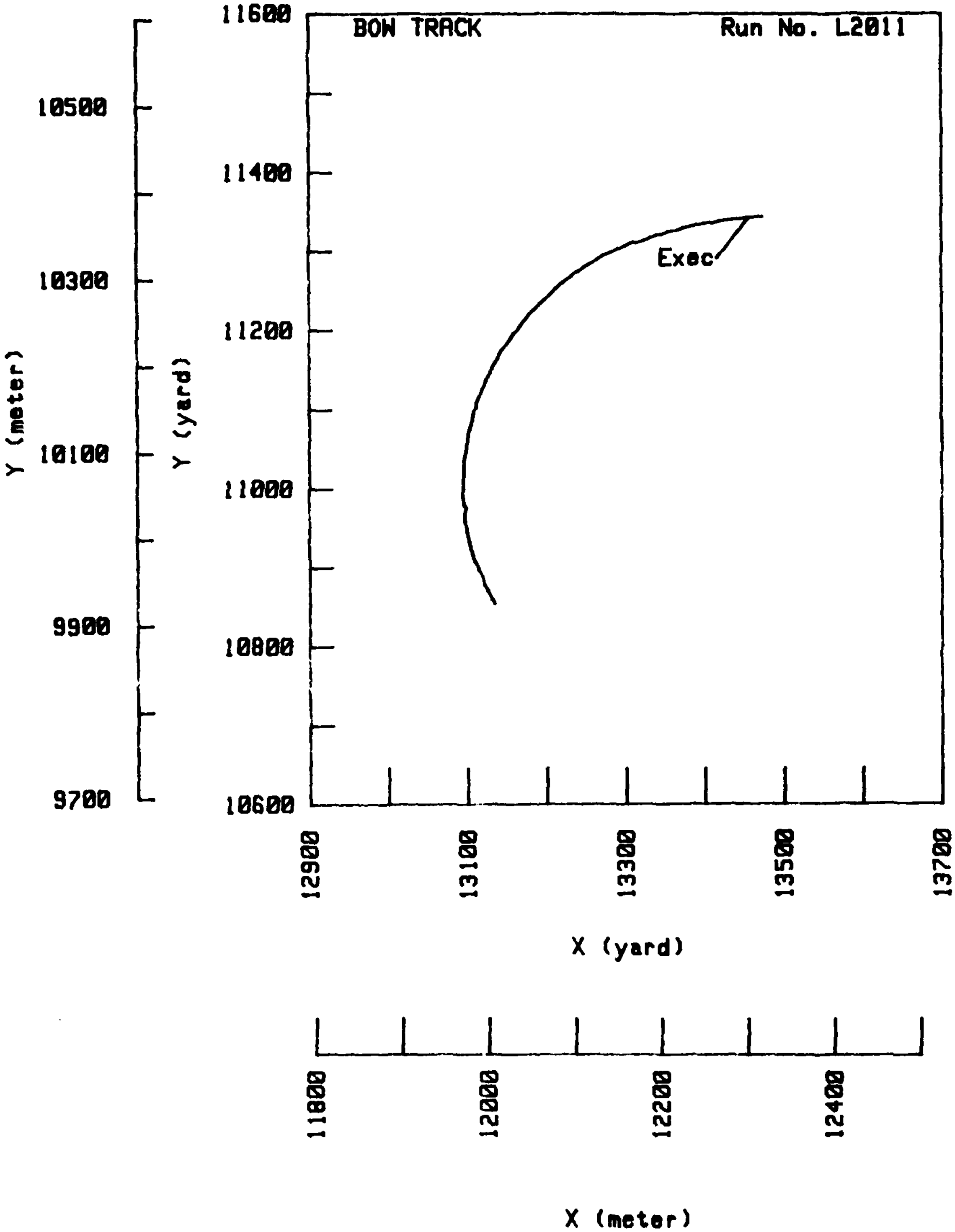

Figure 45 - Position Plot for Full Ahead, 35 Degrees Left Rudder Turning Maneuver (Run L2011)

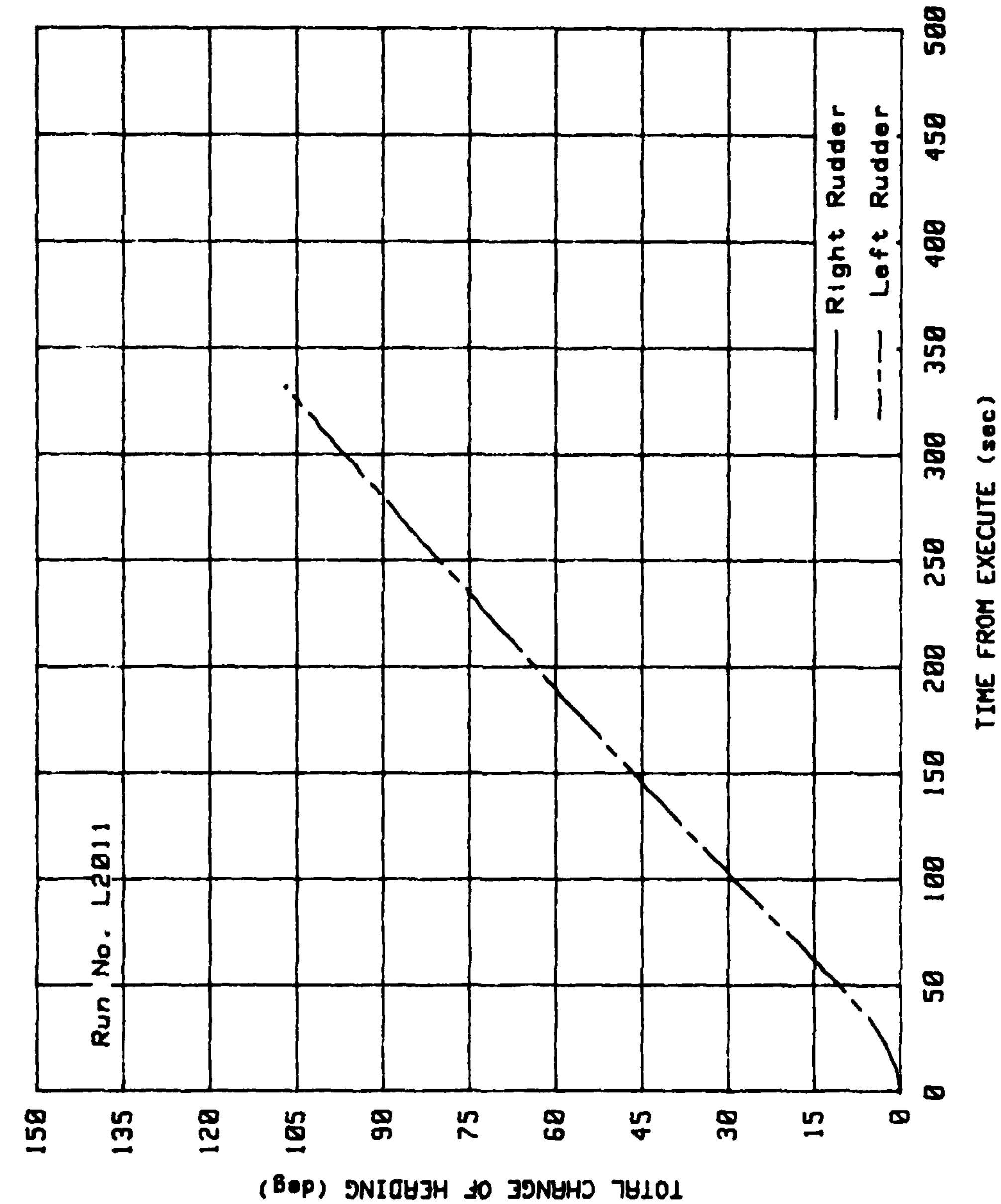

Figure 46 - Change of Heading Plot for Full Ahead, 35 Degrees Left Rudder Turning Maneuver (Run L2011)

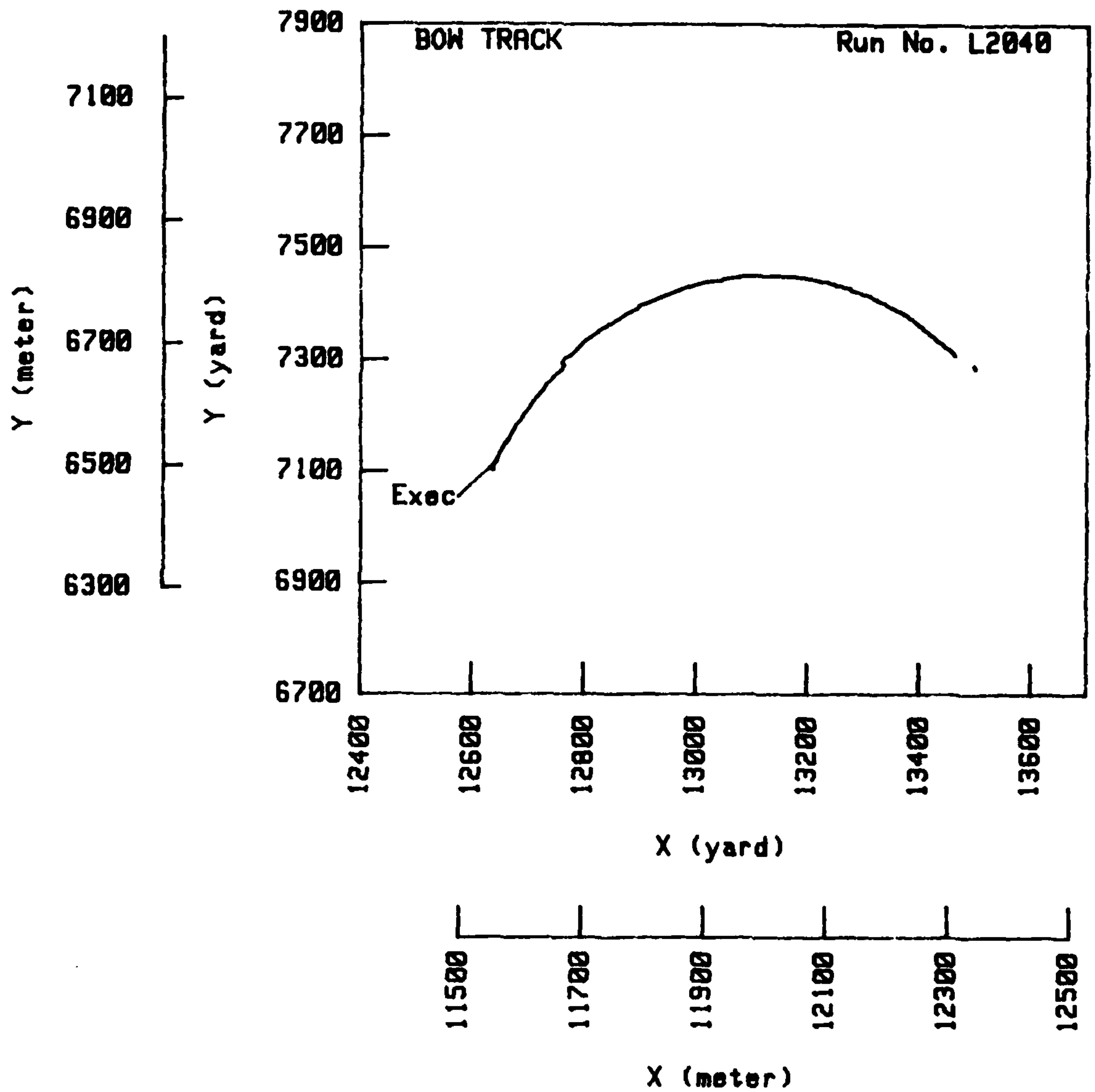

Figure 47 - Position Plot for Full Ahead, 20 Degrees Right Rudder Turning Maneuver (Run L2040)

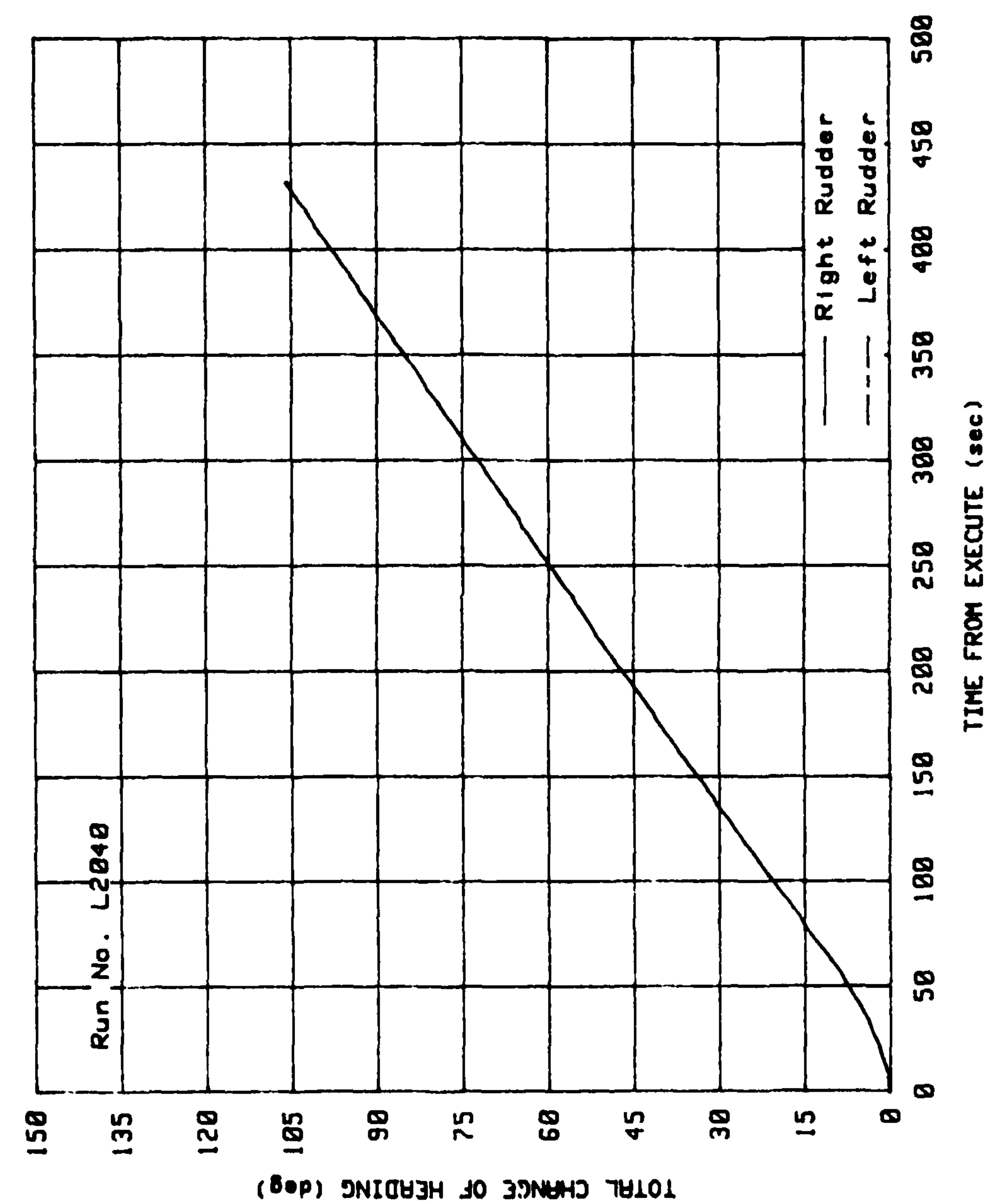

Figure 48 - Change of Heading Plot for Full Ahead, 20 Degrees Right Rudder Turning Maneuver (Run L2040)

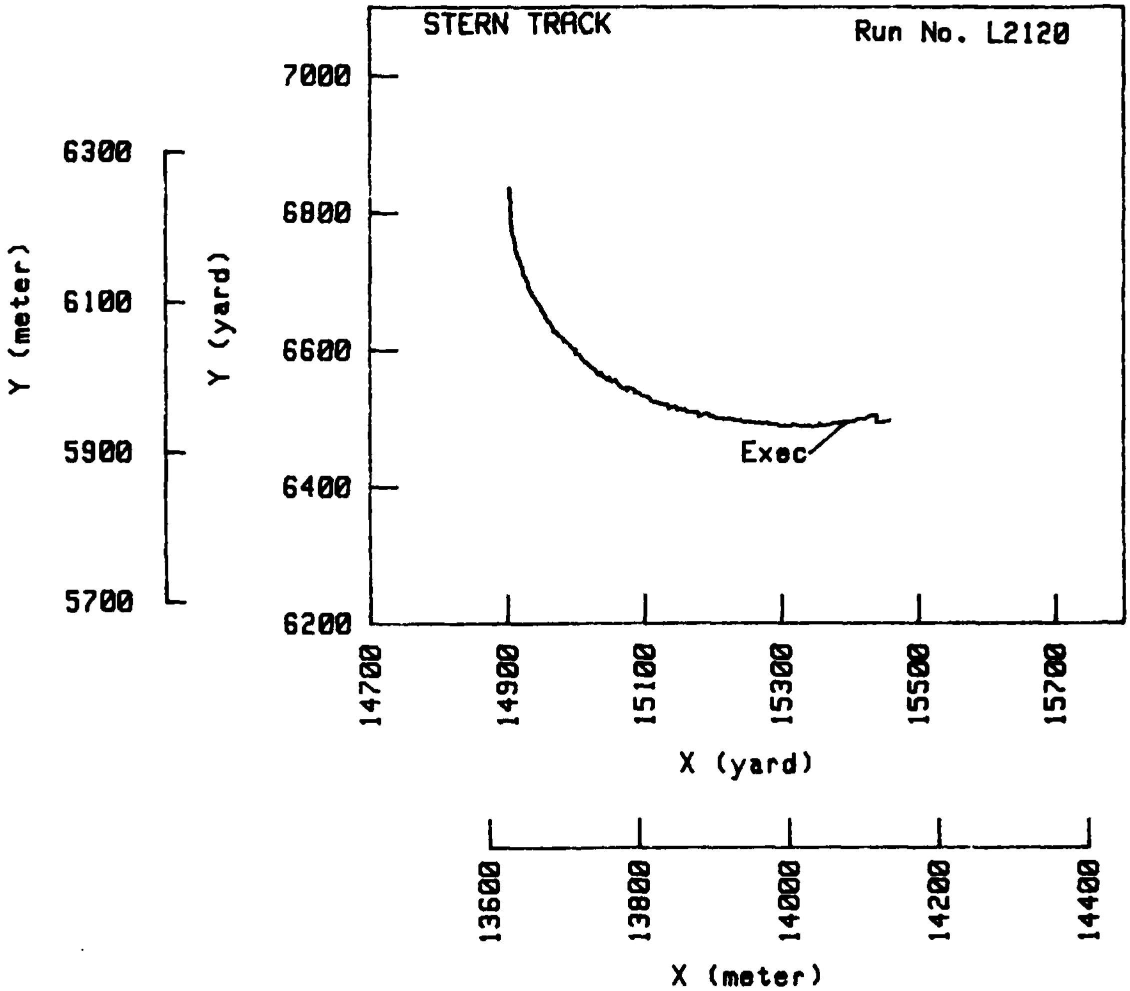

Figure 49 - Position Plot for Half Astern, 35 Degrees Left Rudder Turning Maneuver (Run L2120)

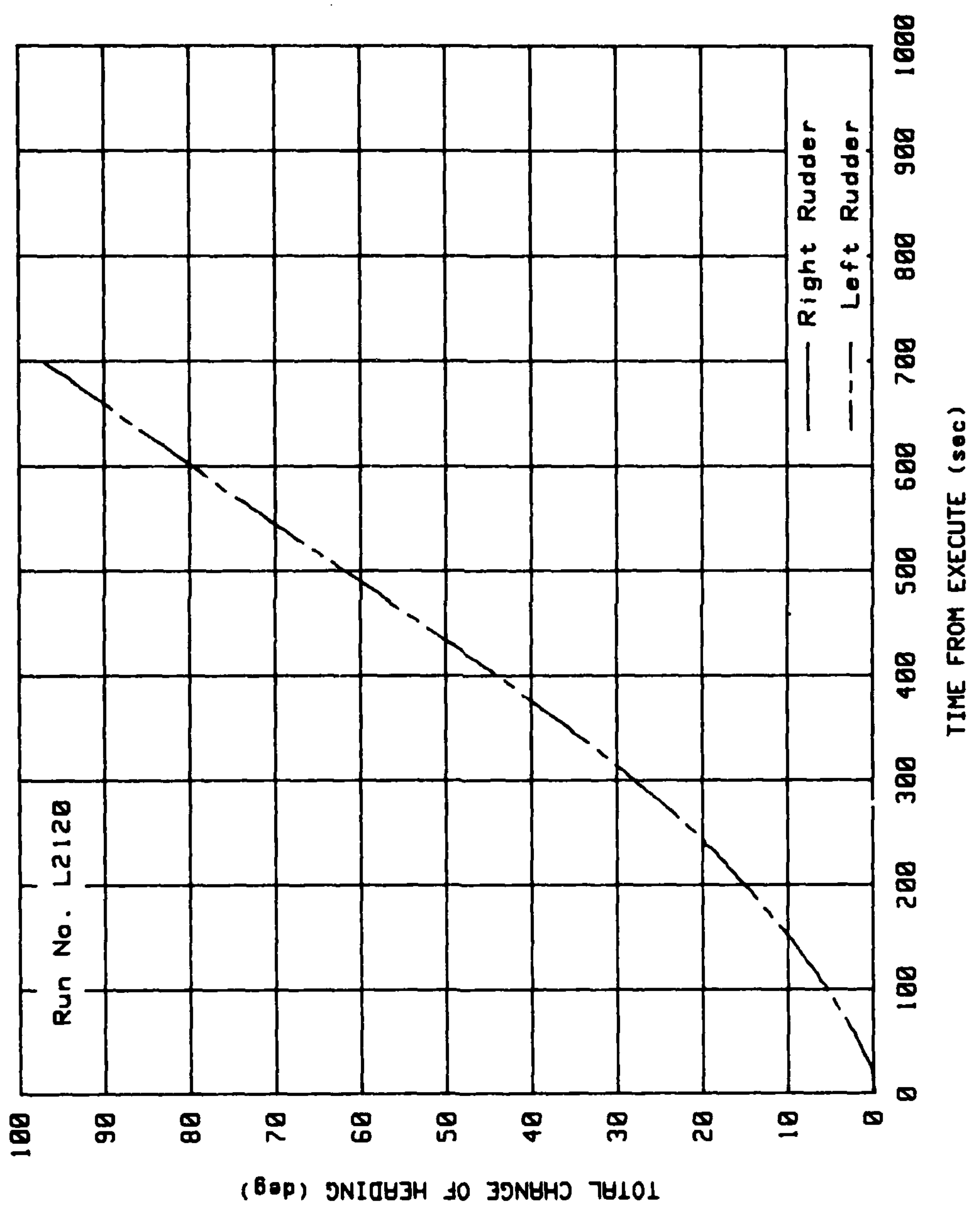

Figure 50 - Change of Heading Plot for Half Astern, 35 Degrees Left Rudder Turning Maneuver (Run L2120)

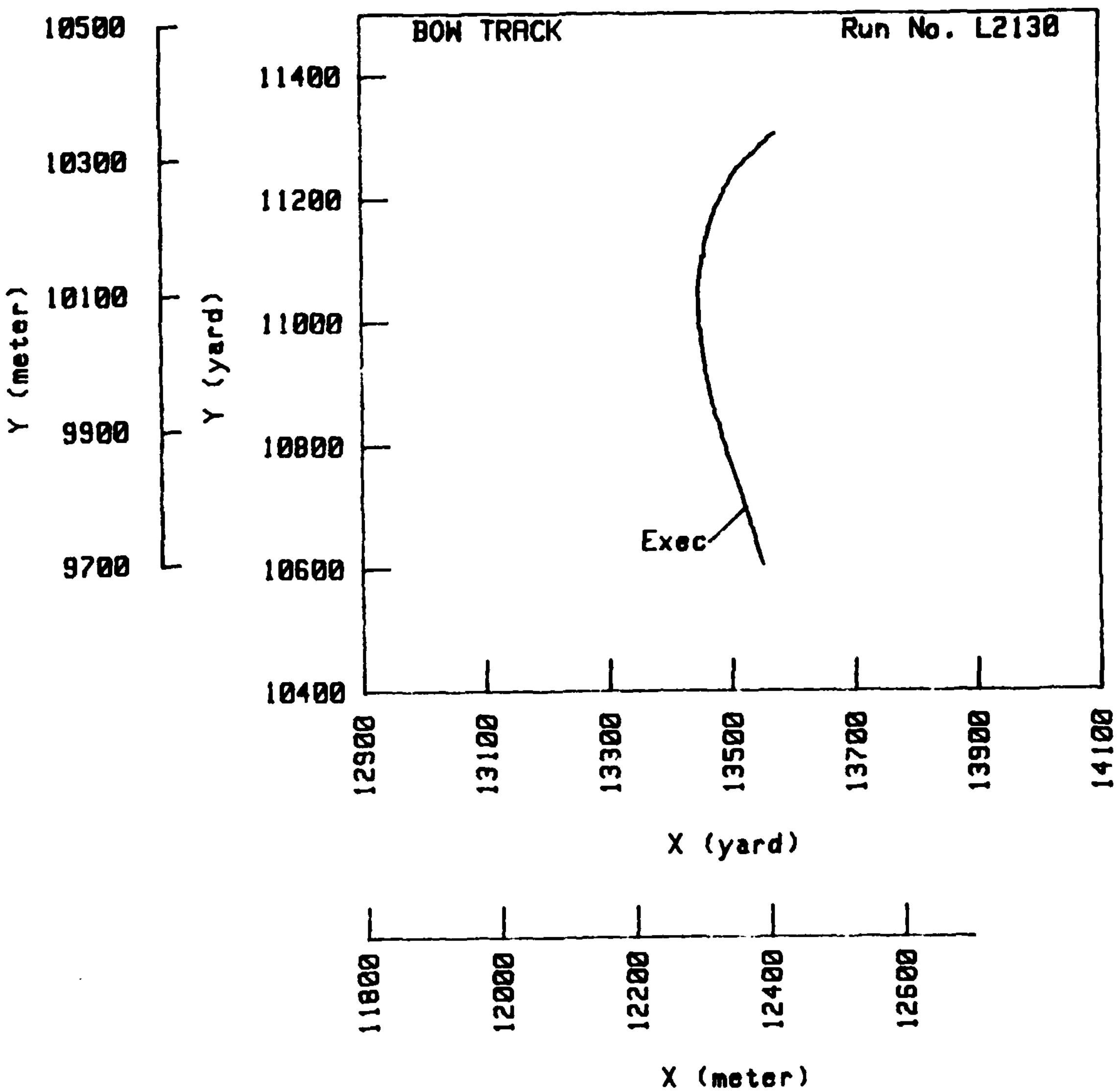

Figure 51 - Position Plot for Full Astern, 35 Degrees Left Rudder Turning Maneuver (Run L2130)

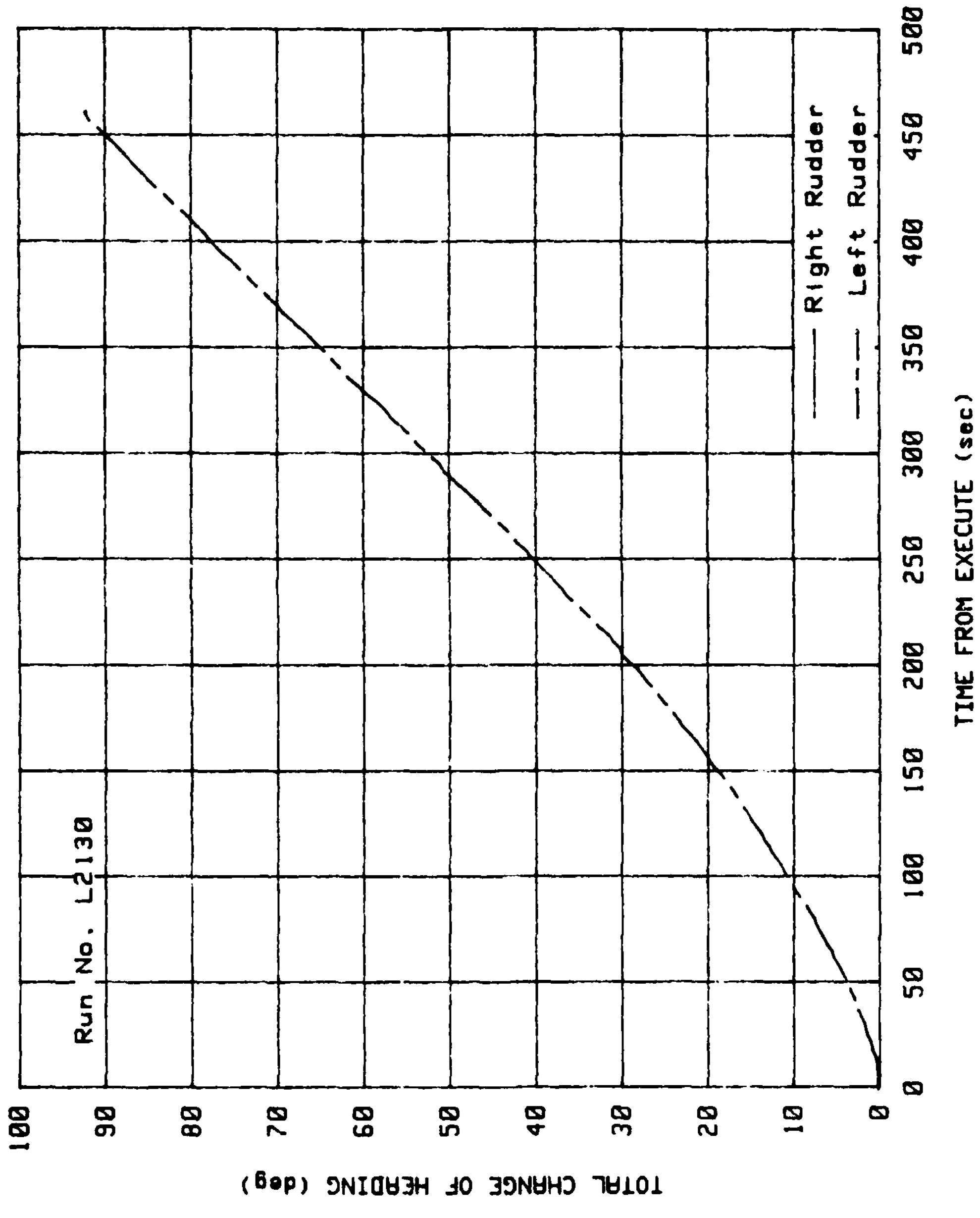

Figure 52 - Change of Heading Plot for Full Astern, 35 Degrees Left Rudder Turning Maneuver (Run L2130)

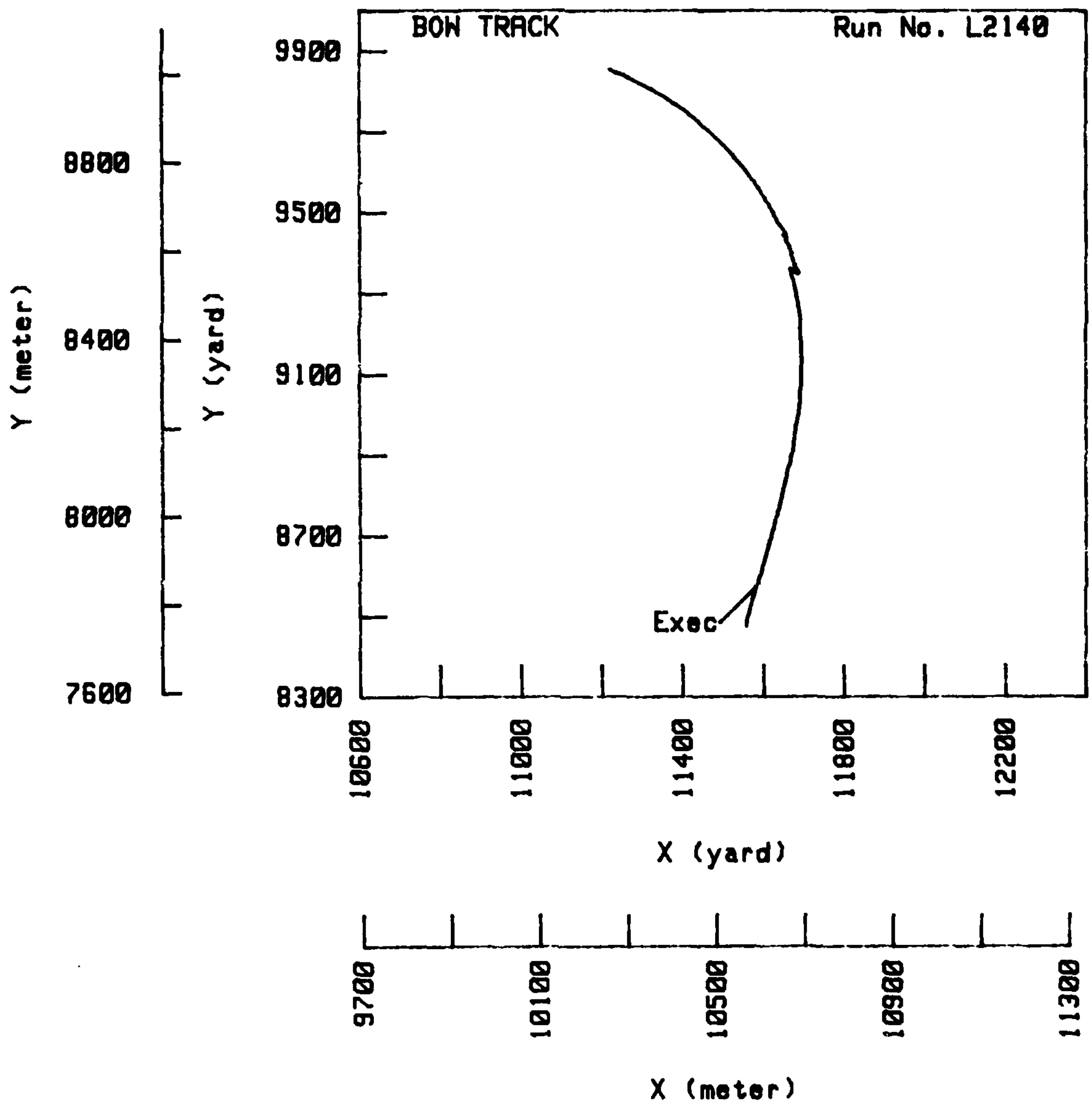

Figure 53 - Position Plot for Full Astern, 10 Degrees Right Rudd.r Turning Maneuver (Run L2140)

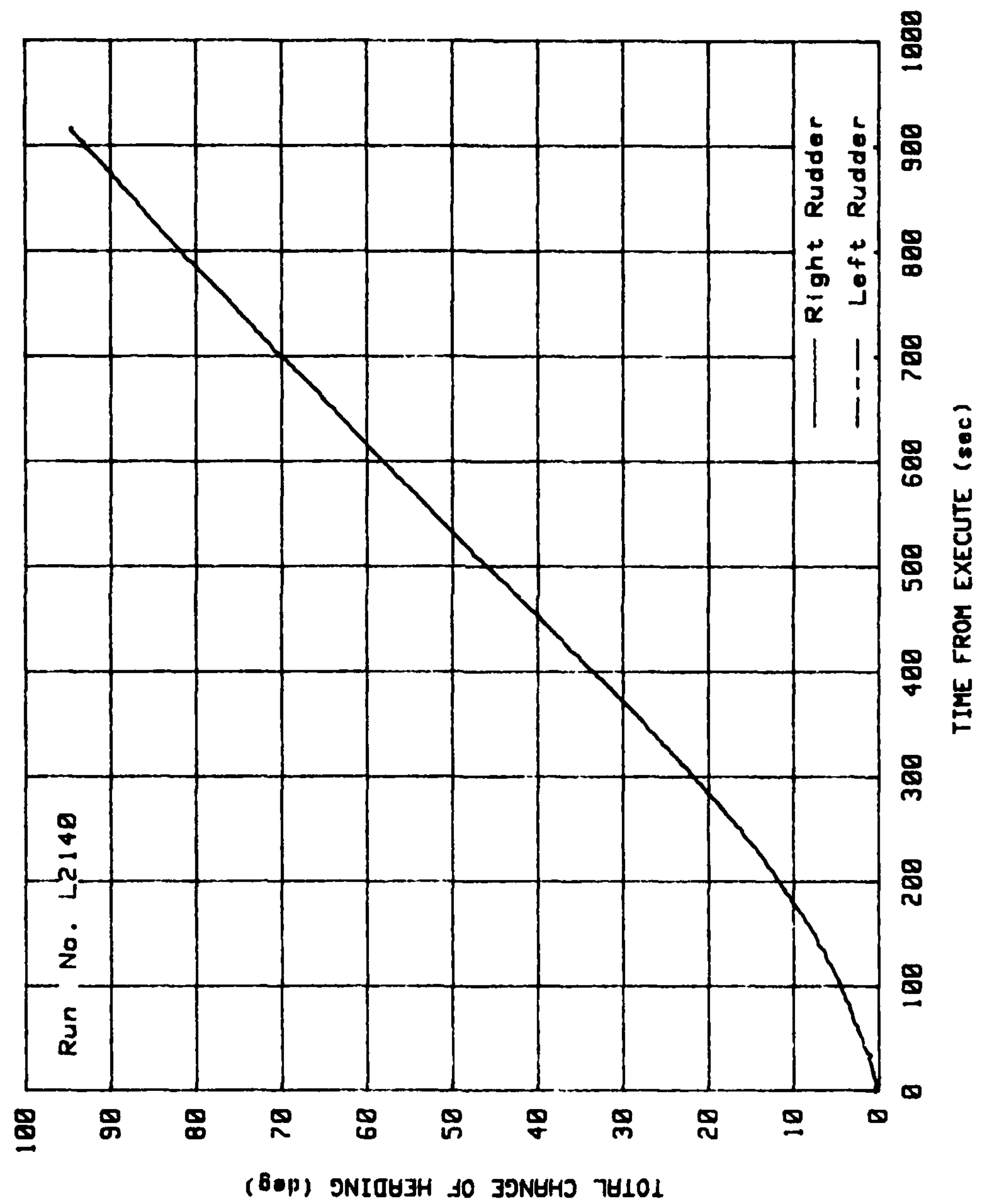

Figure 54 - Change of Heading Plot for Full Astern, 10 Degrees Right Rudder Turning Maneuver (Run L2140)

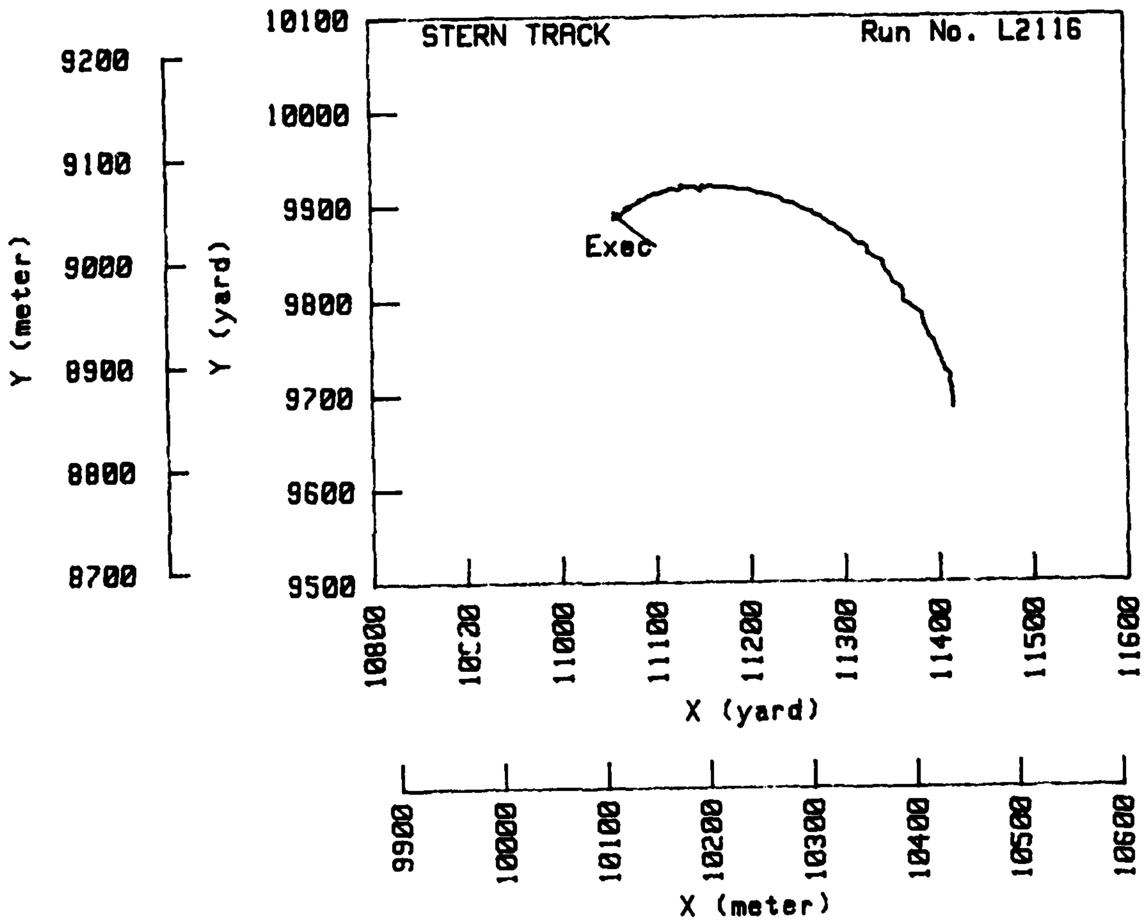

Figure 55 - Position Plot for All Stop to Full Ahead, 35 Degrees Right Rudder Turning Maneuver (Run L2116)

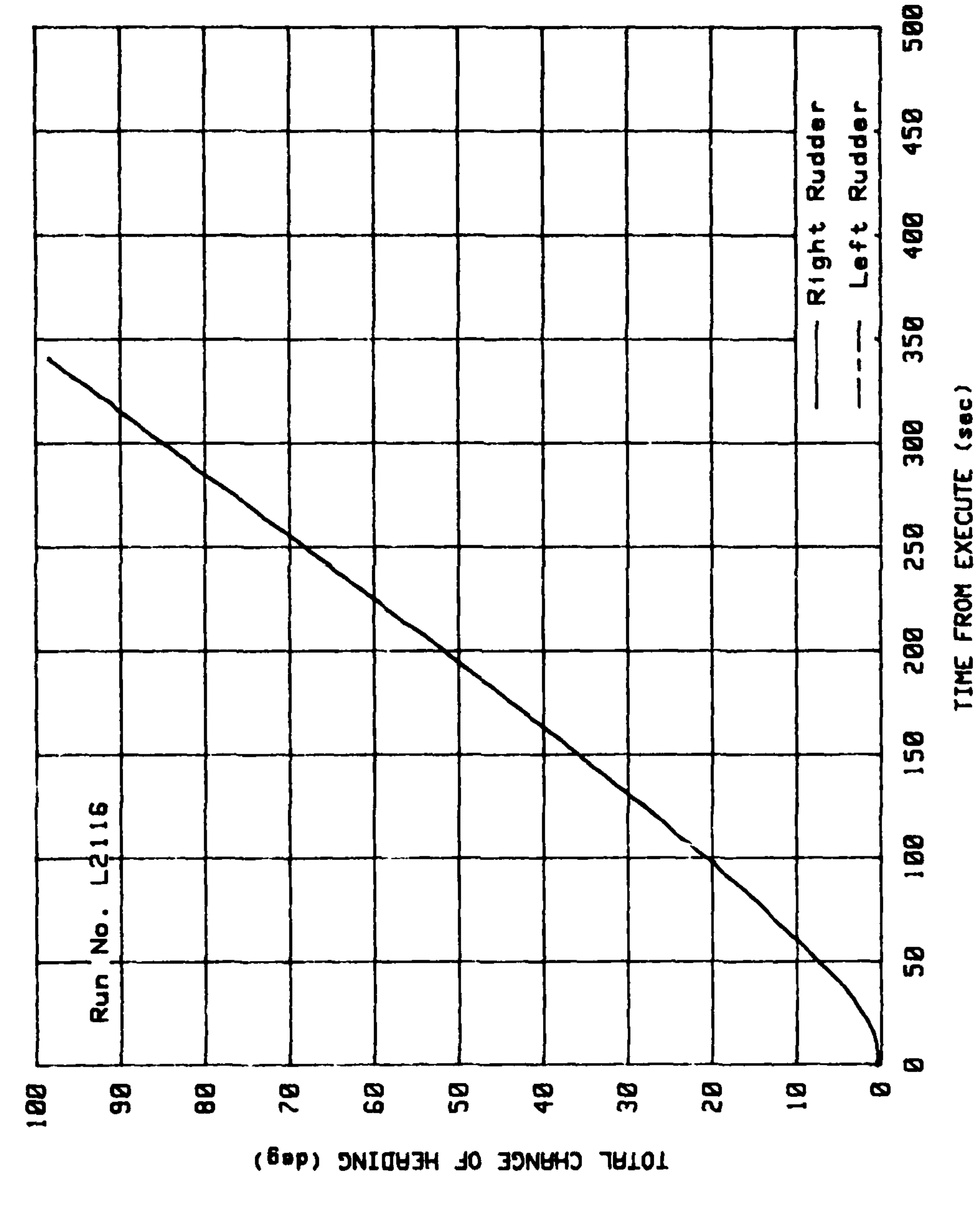

Figure 56 - Change of Heading Plot for All Stop to Full Ahead, 35 Degrees Right Rudder Turning Maneuver (Run L2116)

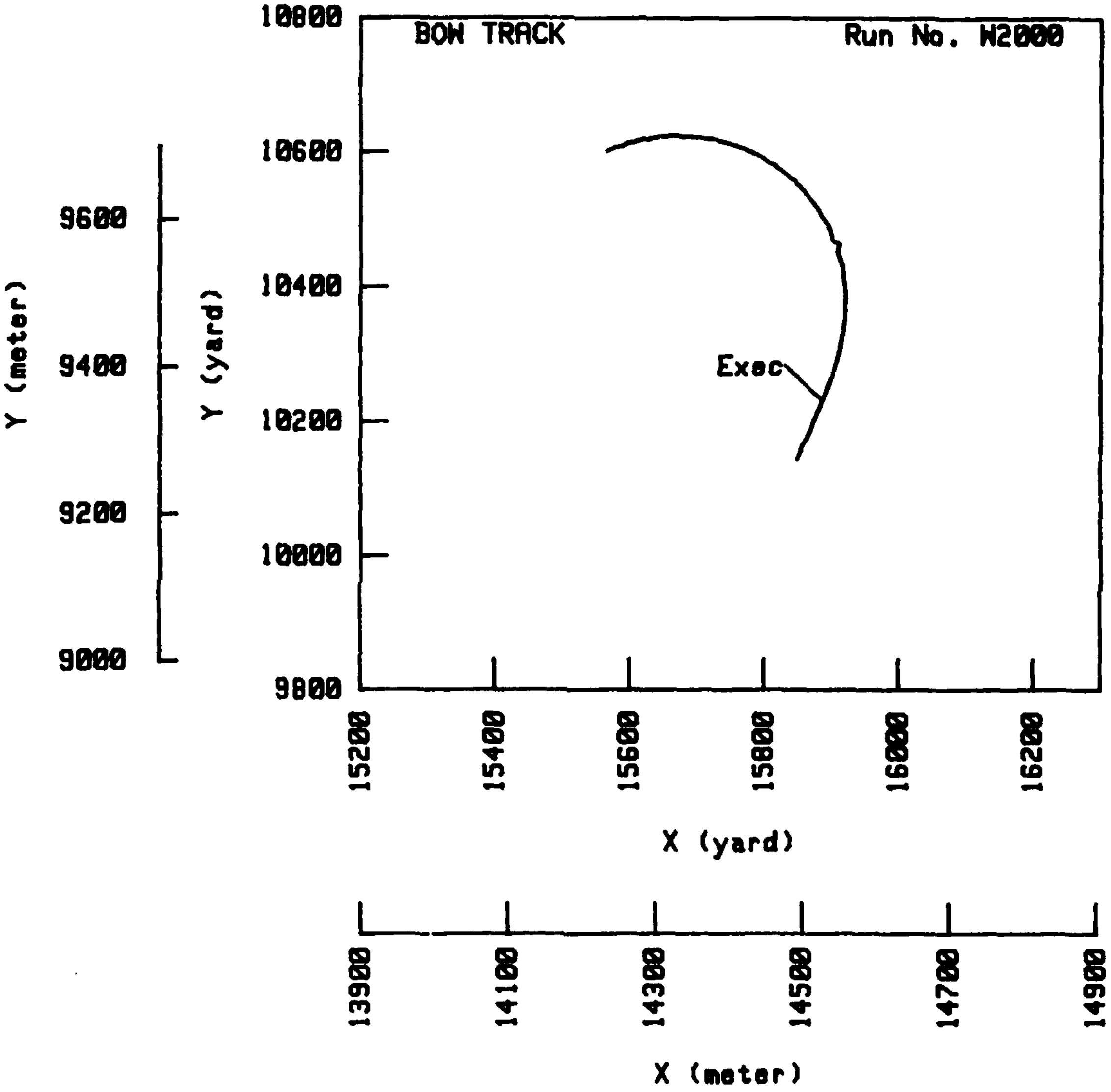

Figure 57 - Position Plot for Half Ahead, 35 Degrees Left Rudder Turning Maneuver (Run W2000)

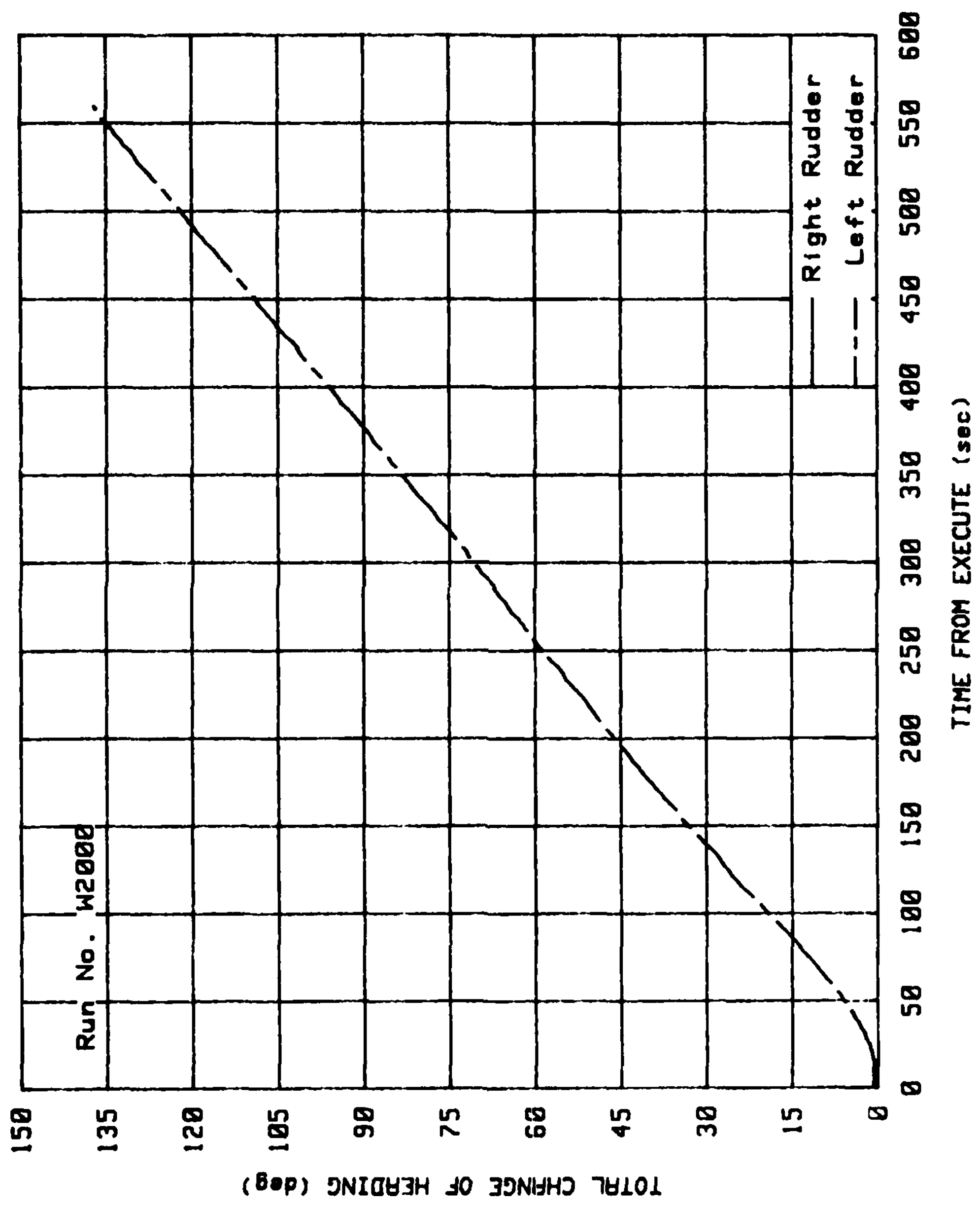

Figure 58 - Change of Heading Plot for Half Ahead, 35 Degrees Left Rudder Turning Maneuver (Run W2000)

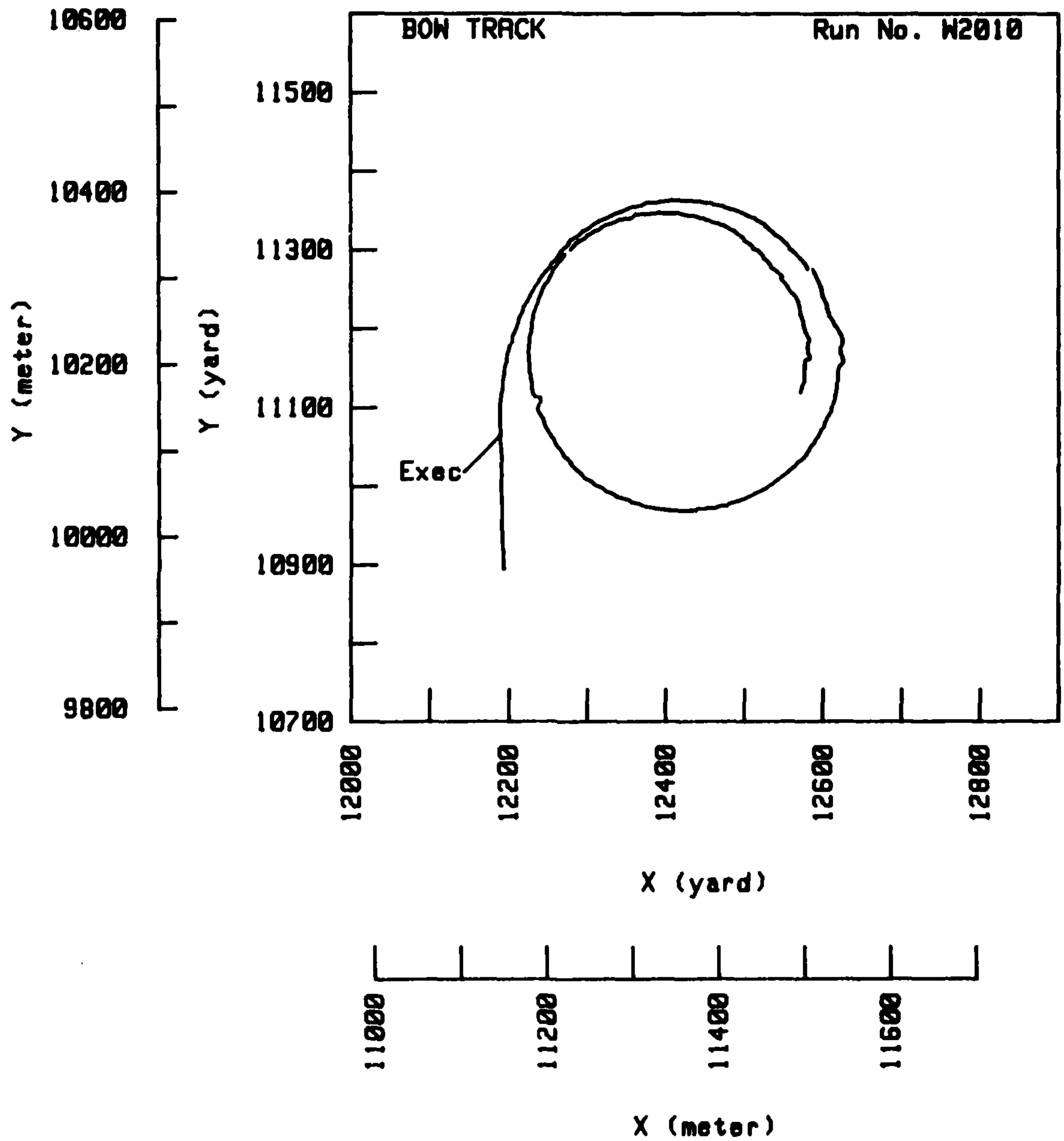

Figure 59 - Position Plot for Full Ahead, 35 Degrees Right Rudder Turning Maneuver (Run W2010)

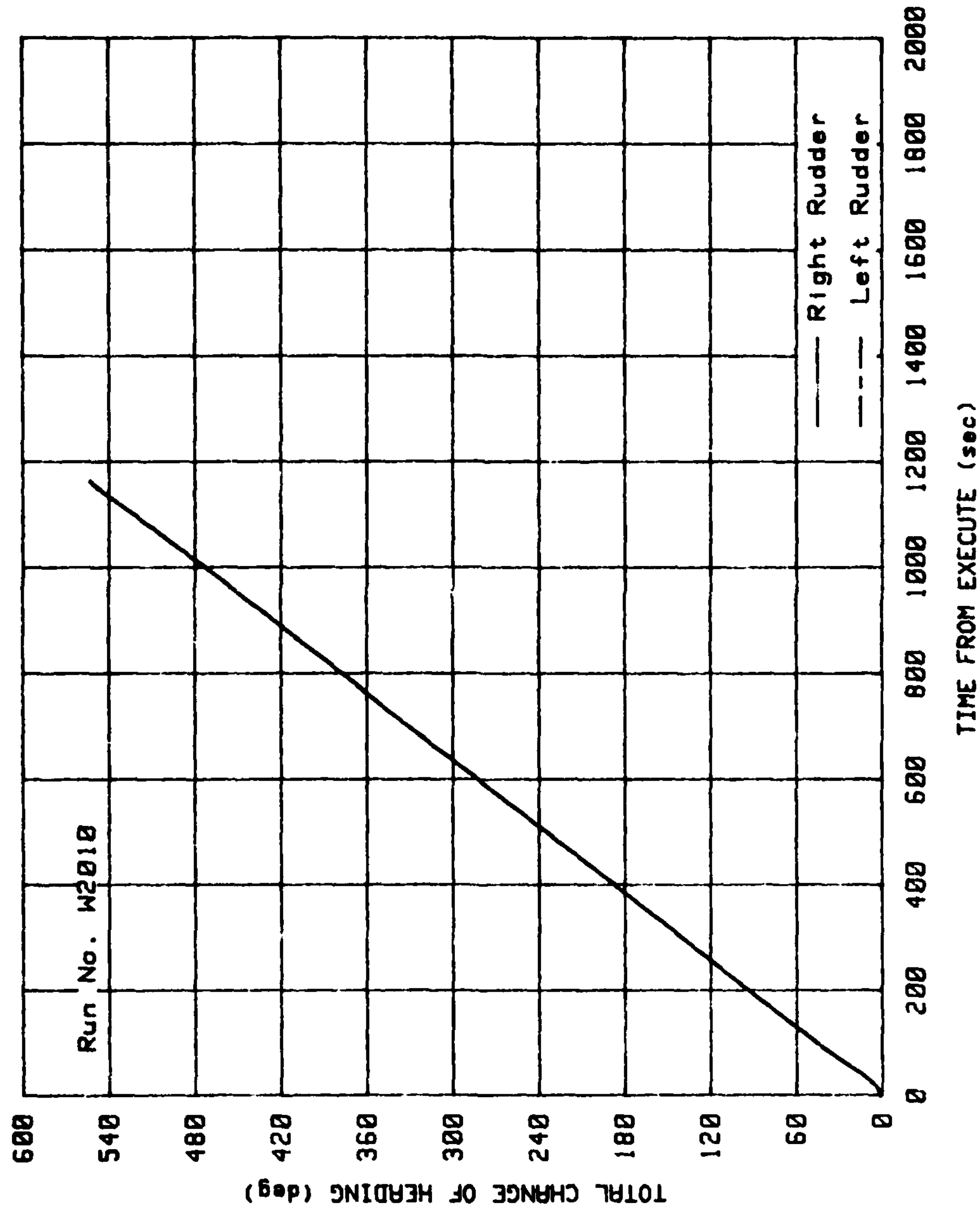

Figure 60 - Change of Heading Plot for Full Ahead, 35 Degrees Right Rudder Turning Maneuver (Run W2010)

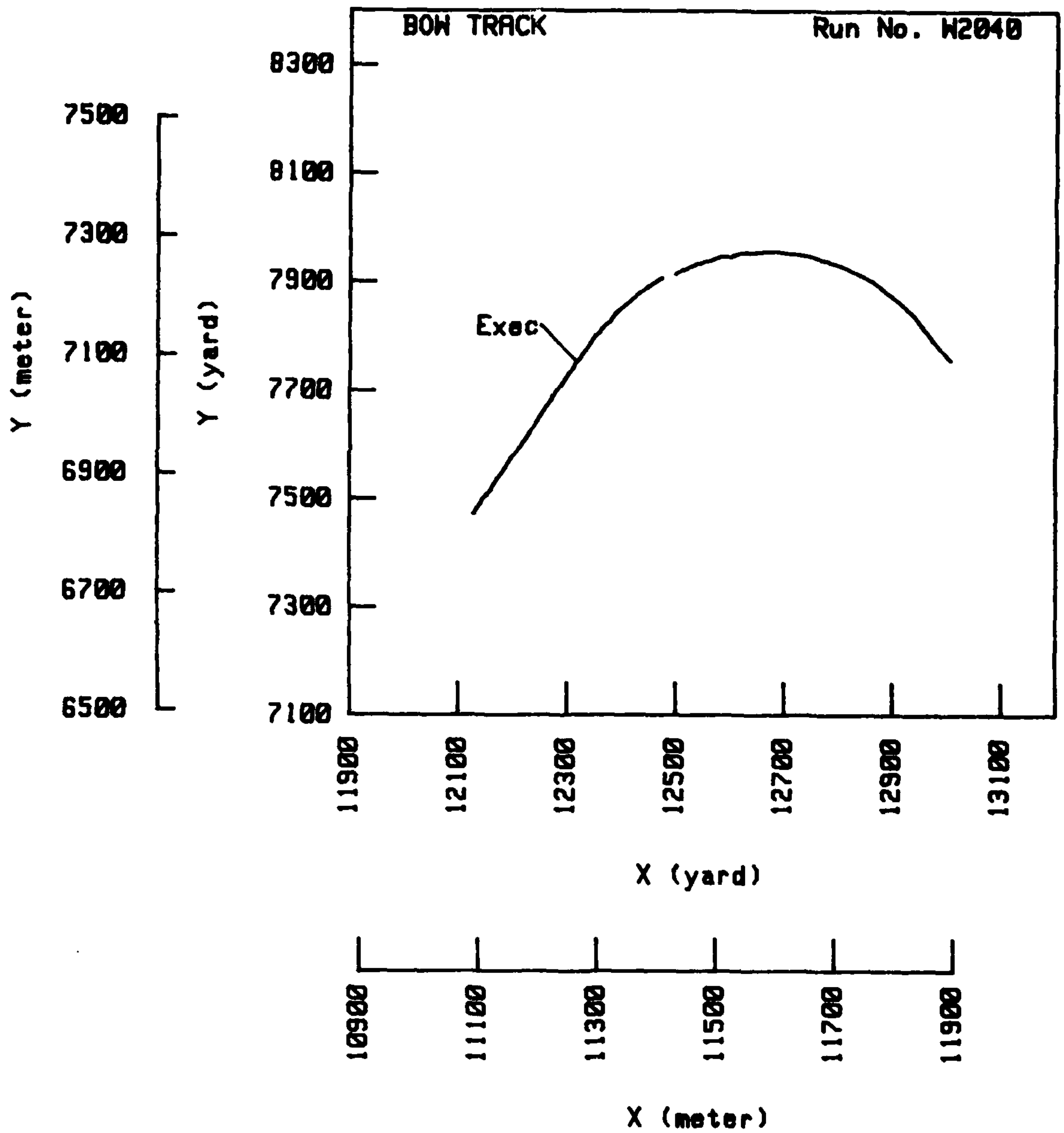

Figure 61 - Position Plot for Full Ahead, 20 Degrees Right Rudder Turning Maneuver (Run W2040)

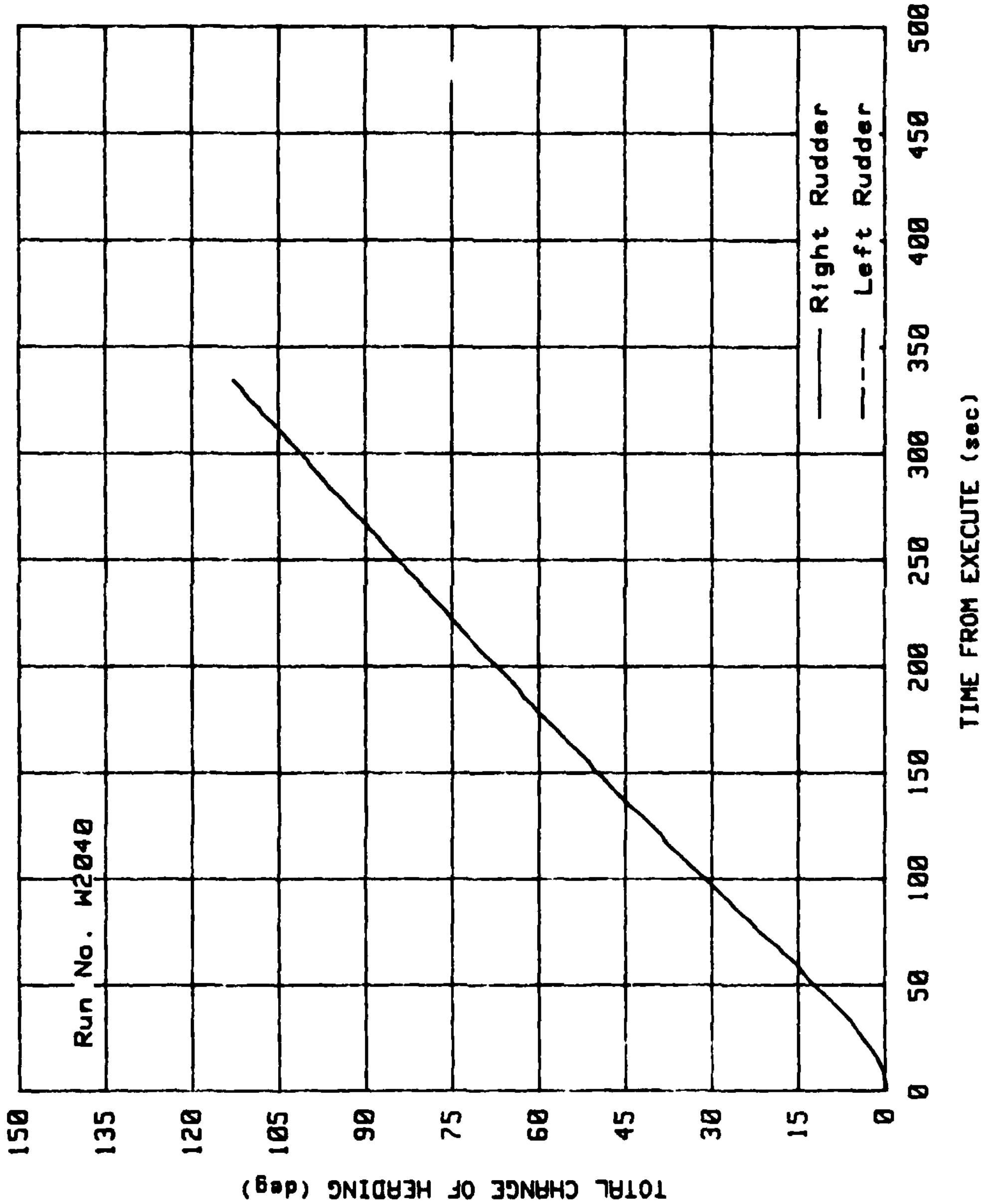

Figure 62 - Change of Heading Plot for Full Ahead, 20 Degrees Right Rudder Turning Maneuver (Run W2040)

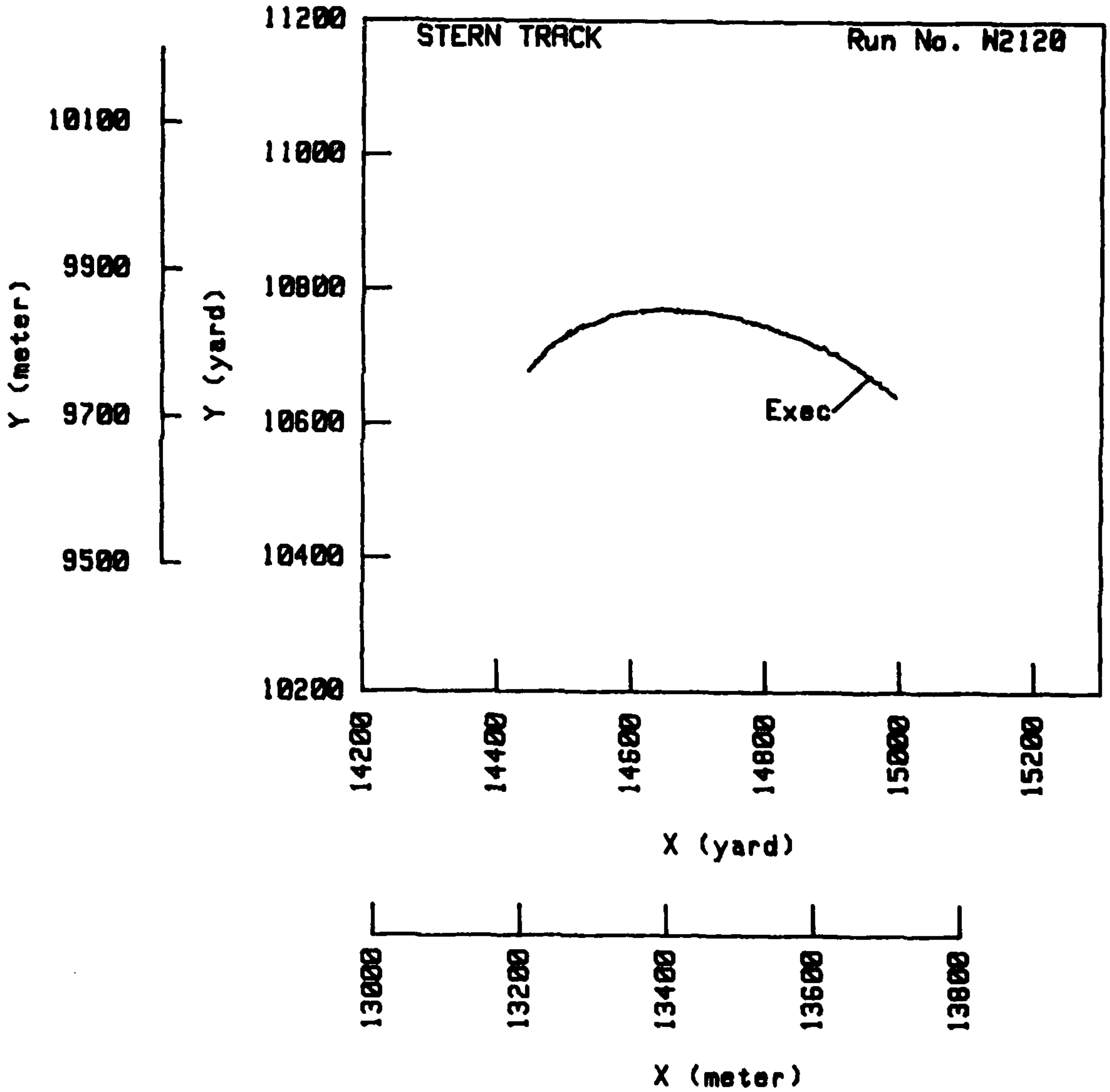

Figure 63 - Position Plot for Half Astern, 35 Degrees Right Rudder Turning Maneuver (Run W2120)

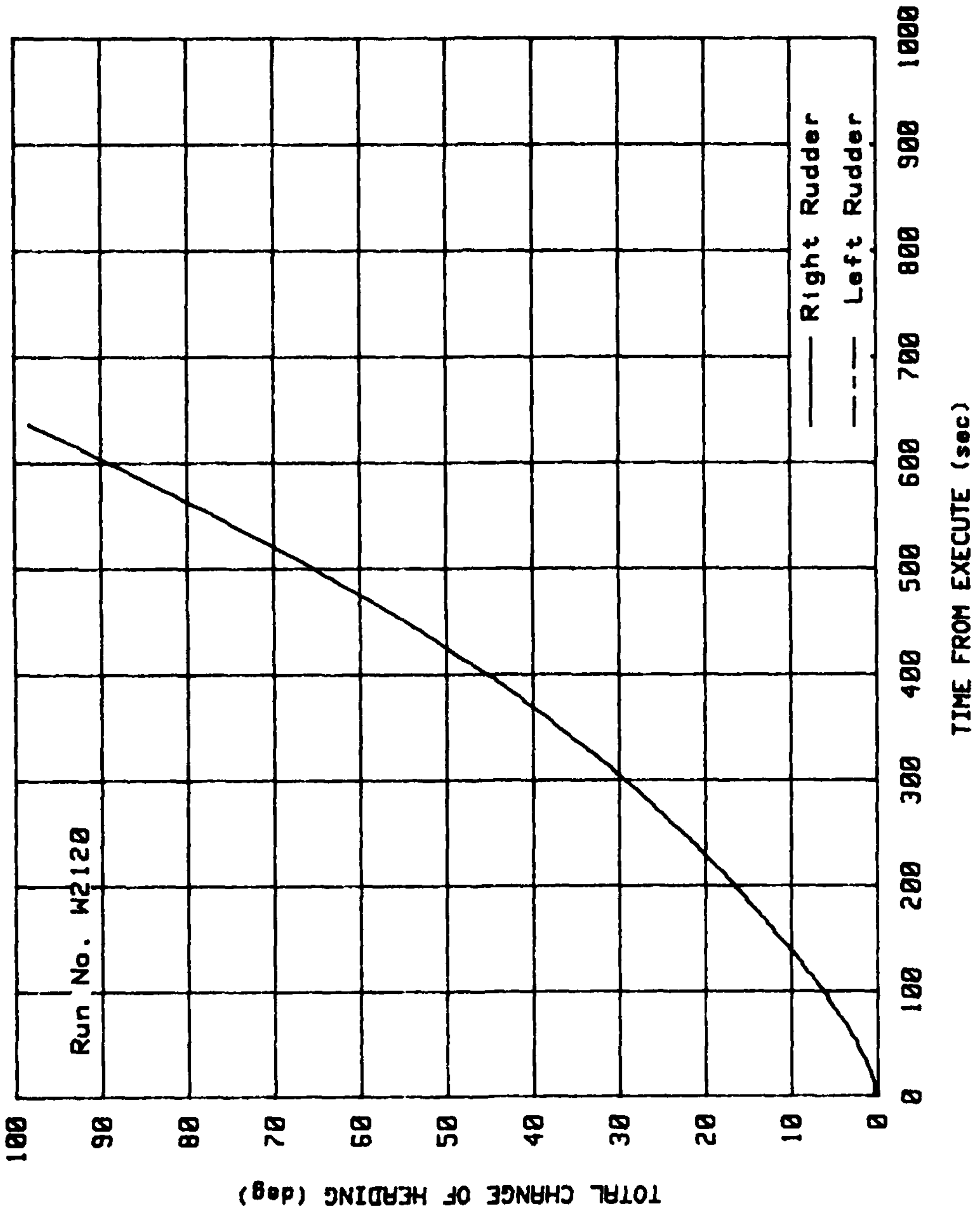

Figure 64 - Change of Heading Plot for Half Astern, 35 Degrees Right Rudder Turning Maneuver (Run W2120)

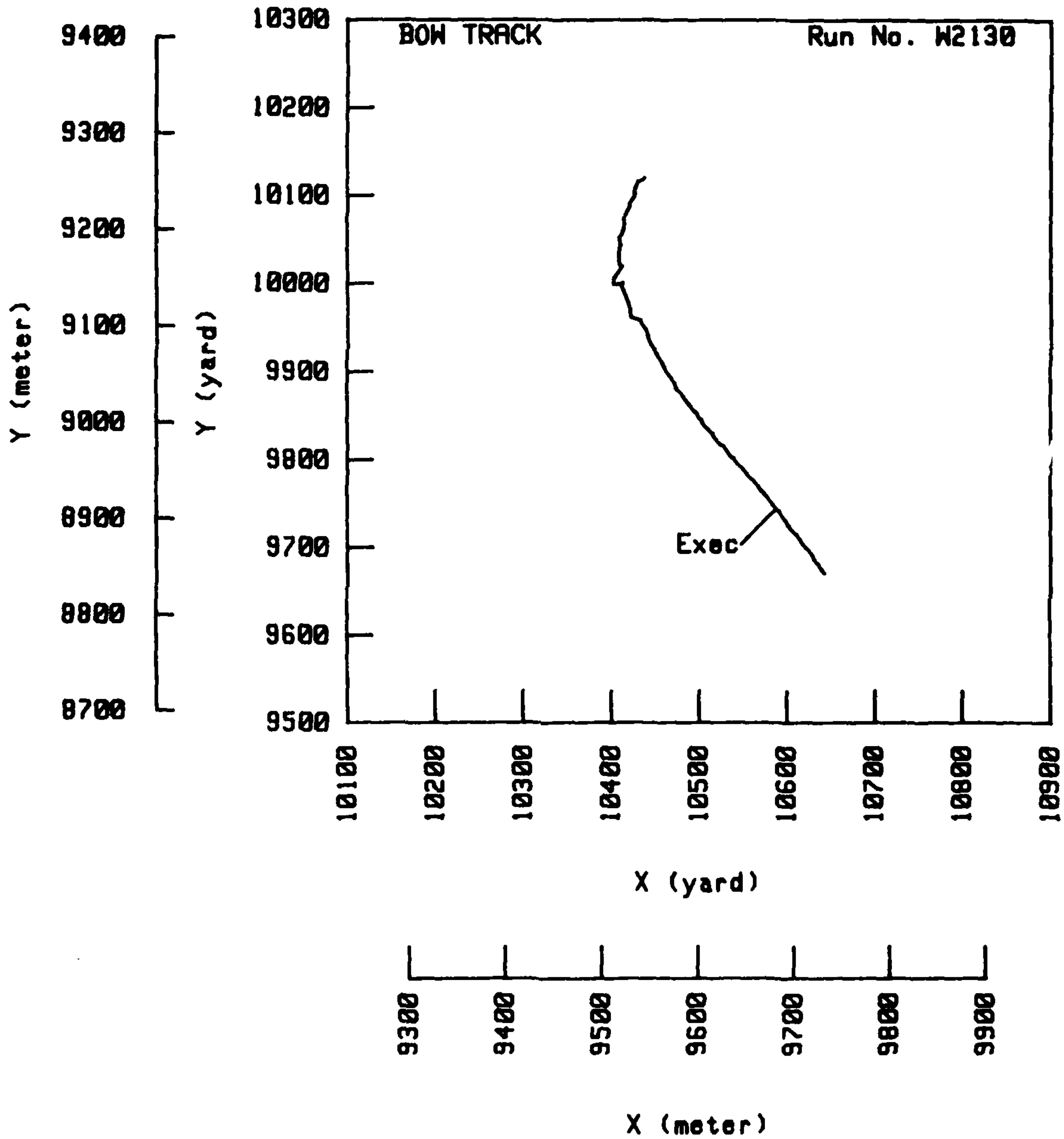

Figure 65 - Position Plot for Full Astern, 35 Degrees Left Rudder Turning Maneuver (Run W2130)

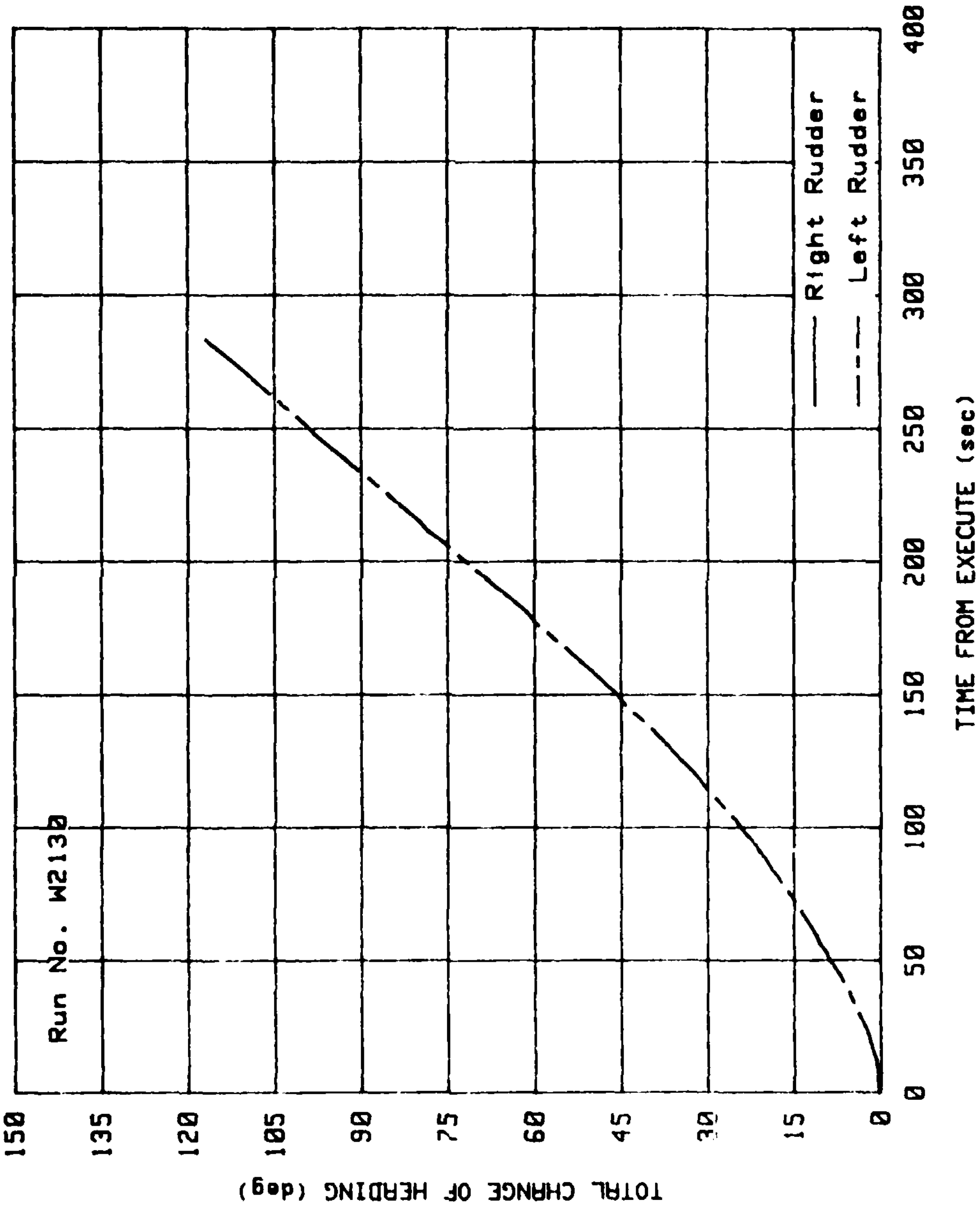

Figure 66 - Change of Heading Plot for Full Astern, 35 Degrees Left Rudder Turning Maneuver (Run W2130)

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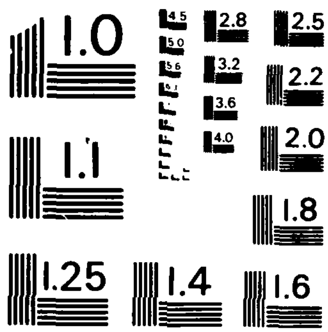

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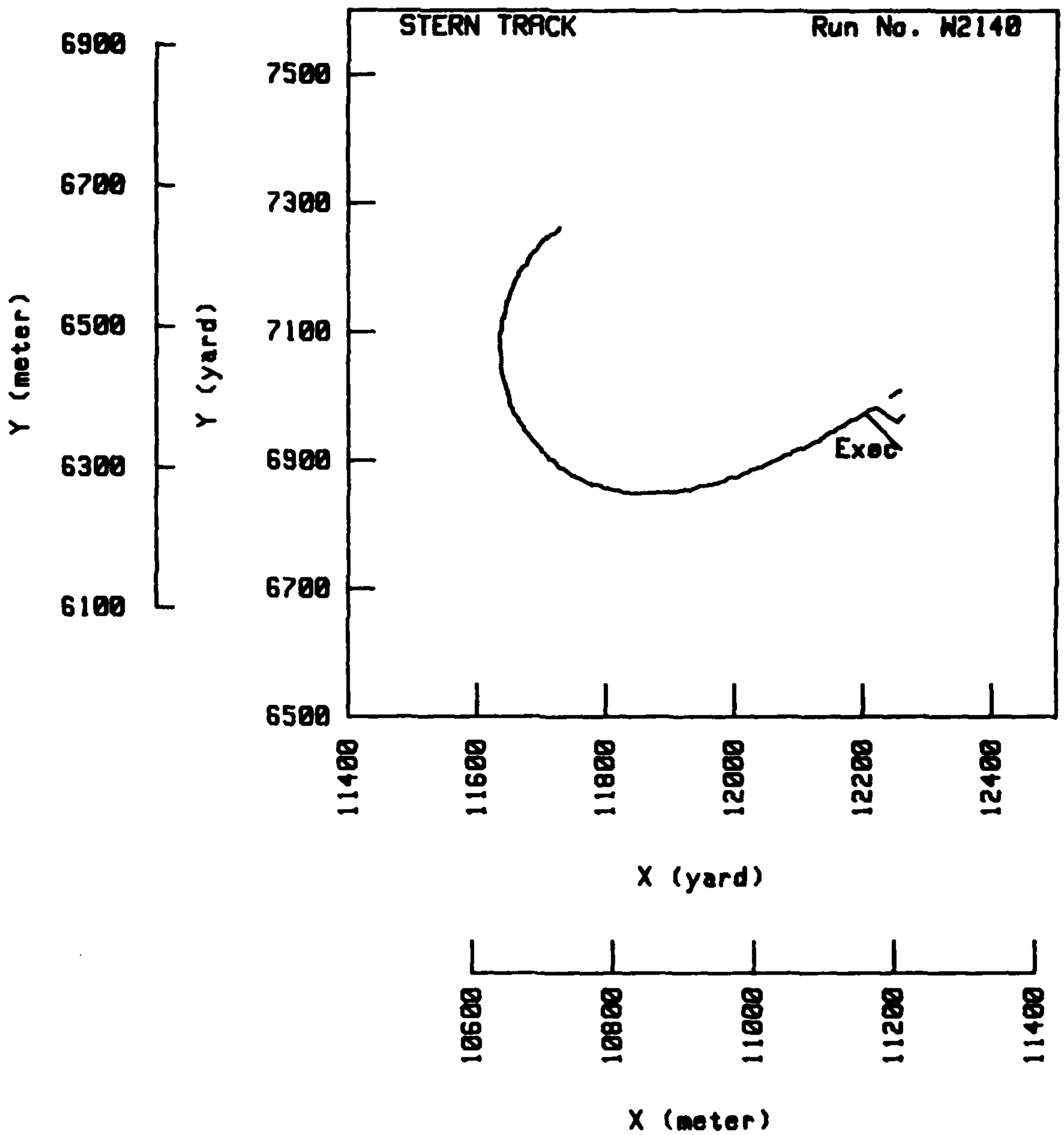


Figure 67 - Position Plot for Full Astern, 20 Degrees Left Rudder Turning Maneuver (Run W2140)

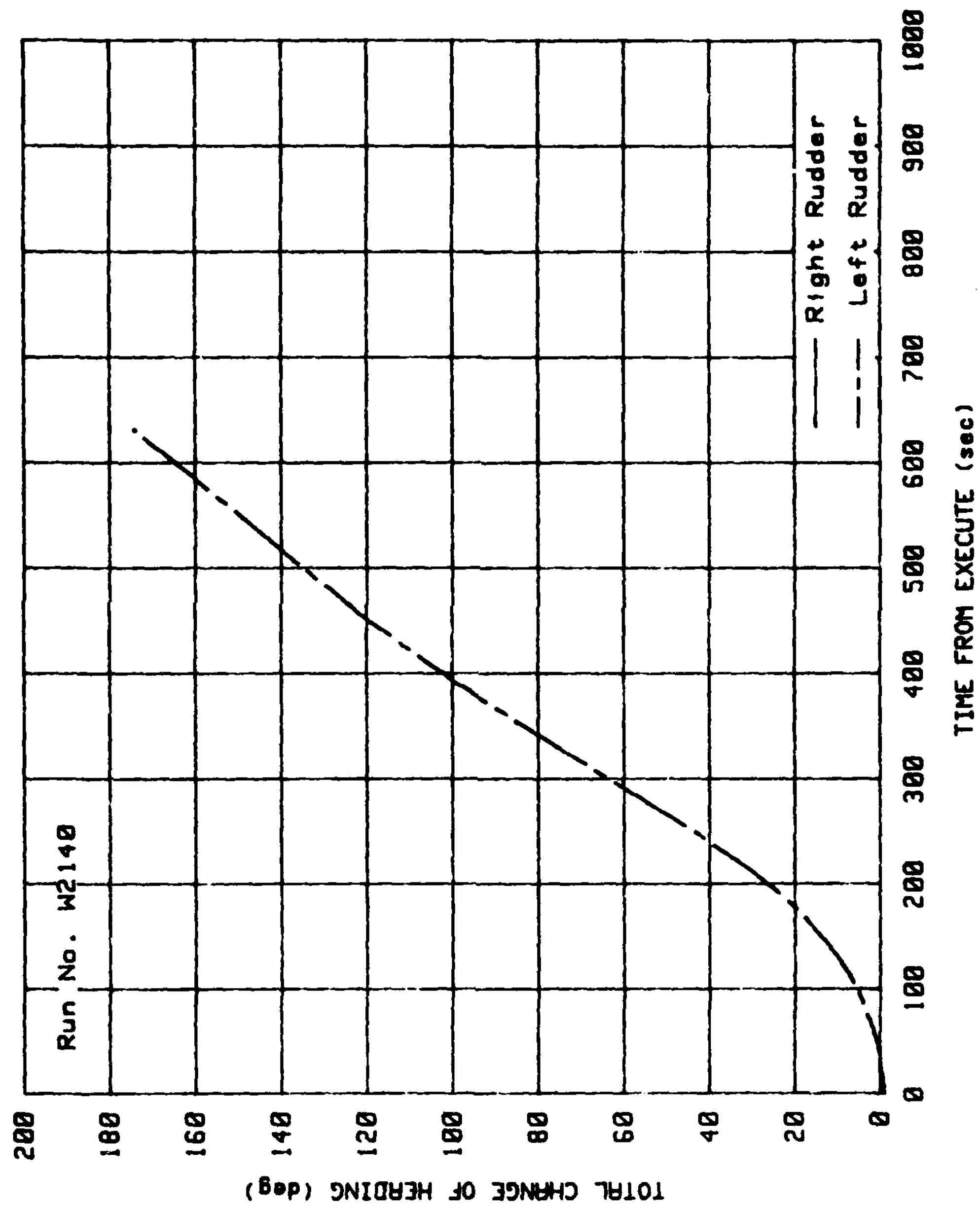


Figure 68 - Change of Heading Plot for Full Astern, 20 Degrees Left Rudder Turning Maneuver (Run W2140)

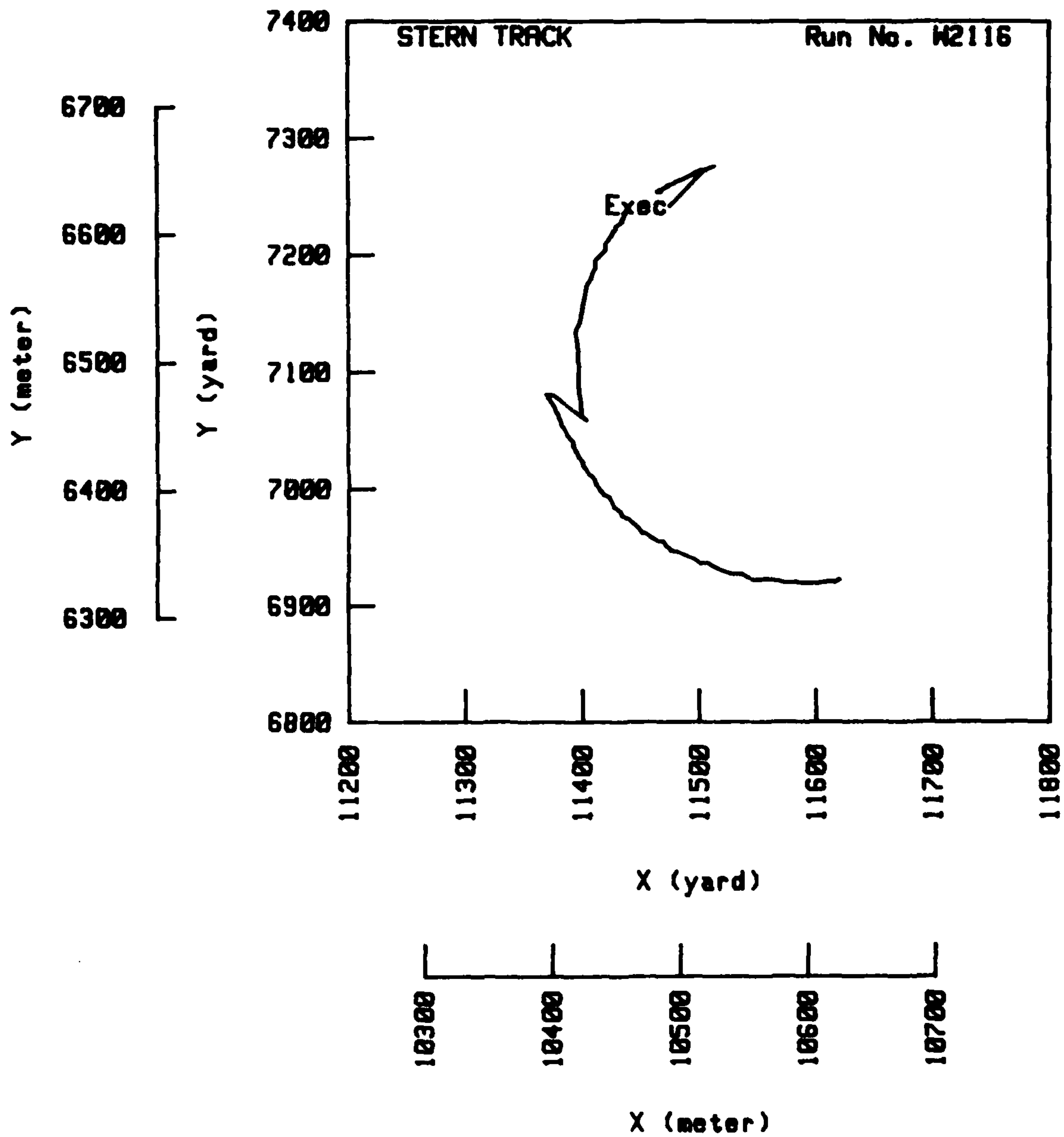


Figure 69 - Position Plot for All Stop to Full Ahead, 35 Degrees Left Rudder Turning Maneuver (Run W2116)

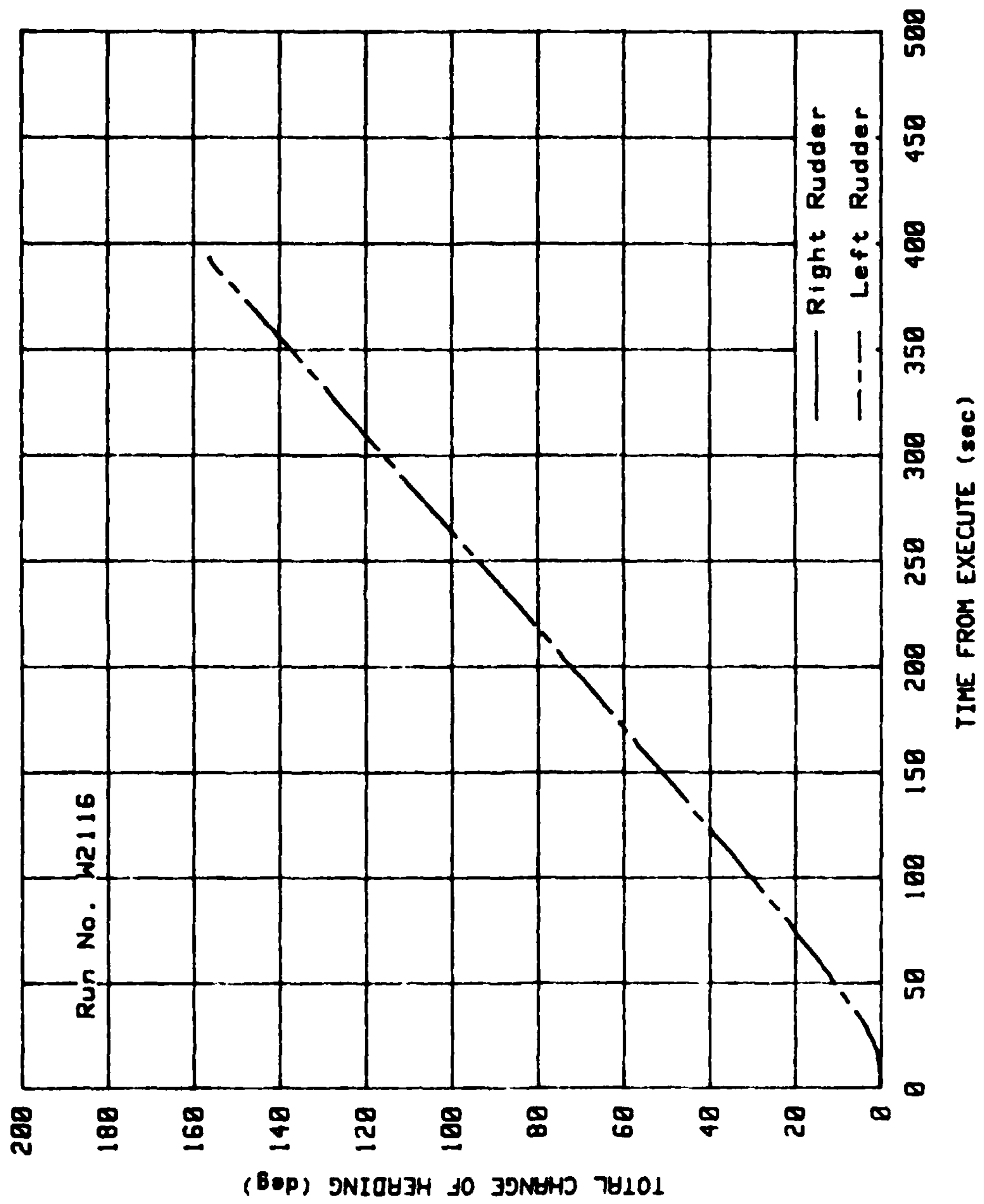


Figure 70 - Change of Heading Plot for All Stop to Full Ahead, 35 Degrees Left Rudder Turning Maneuver (Run W2116)

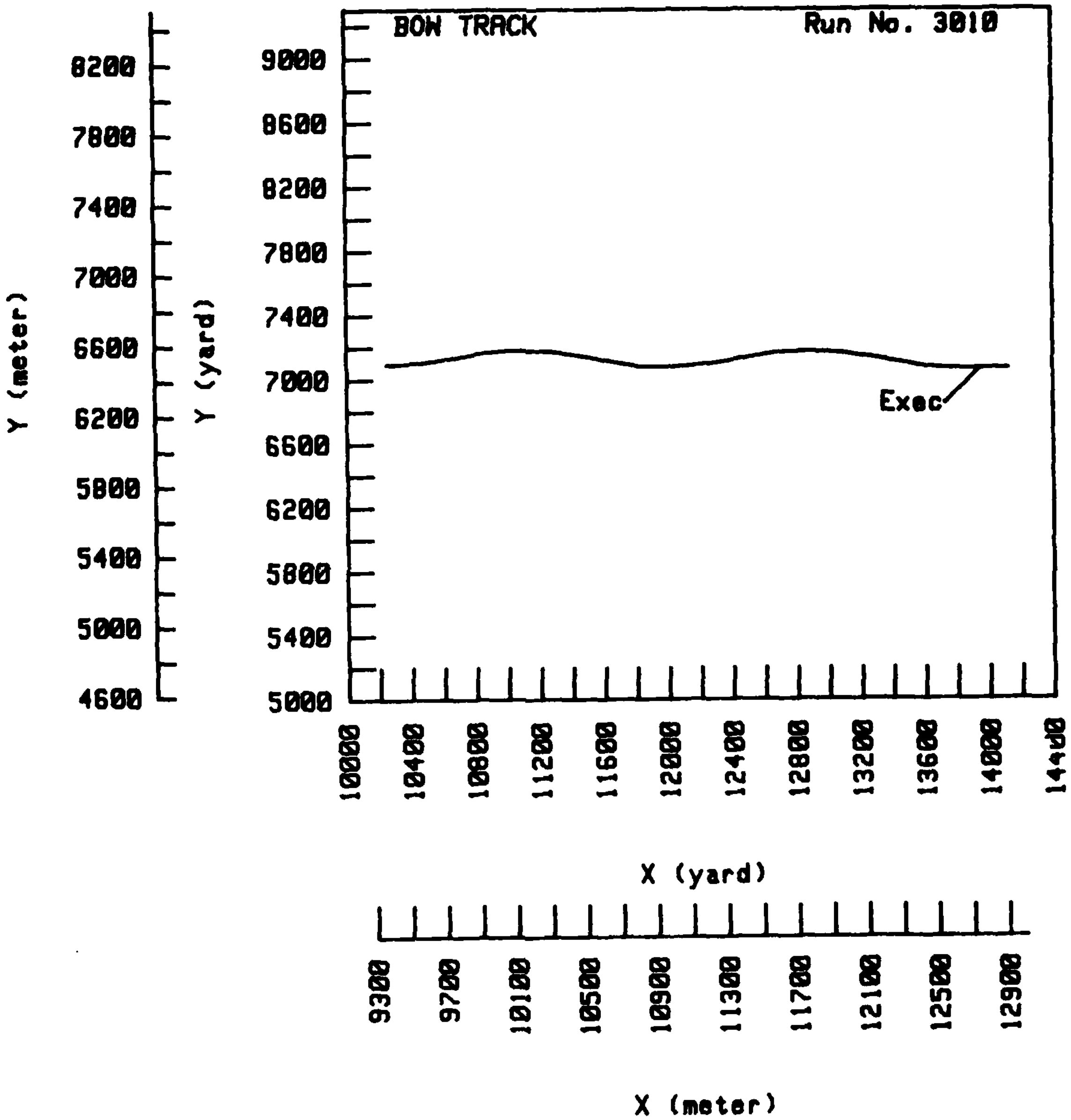


Figure 71 - Position Plot for Full Ahead, 10/10 Degrees Overshoot Maneuver (Run 3010)

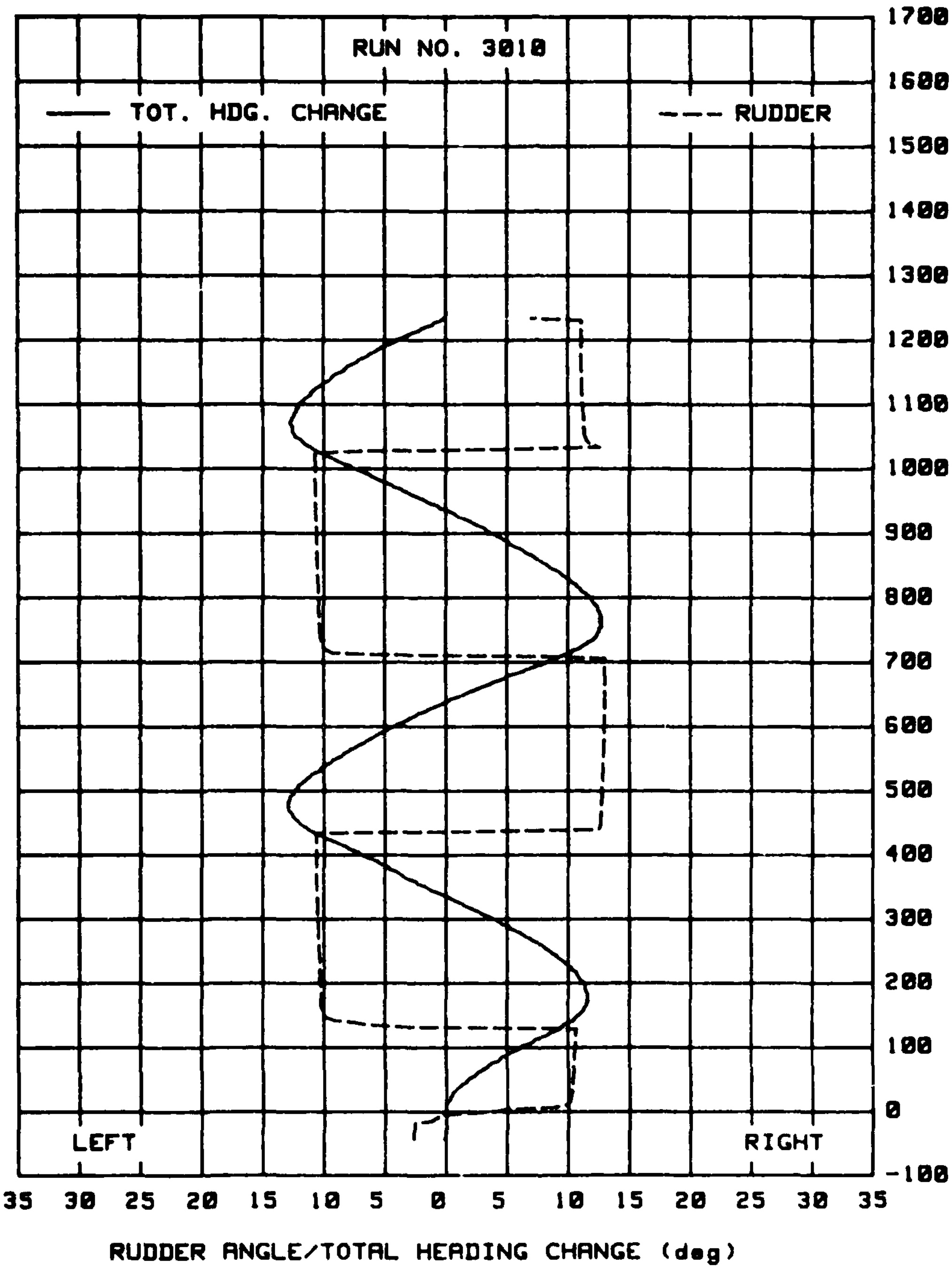


Figure 72 - Rudder and Heading Changes during Full Ahead, 10/10 Degrees Overshoot Maneuver (Run 3010)

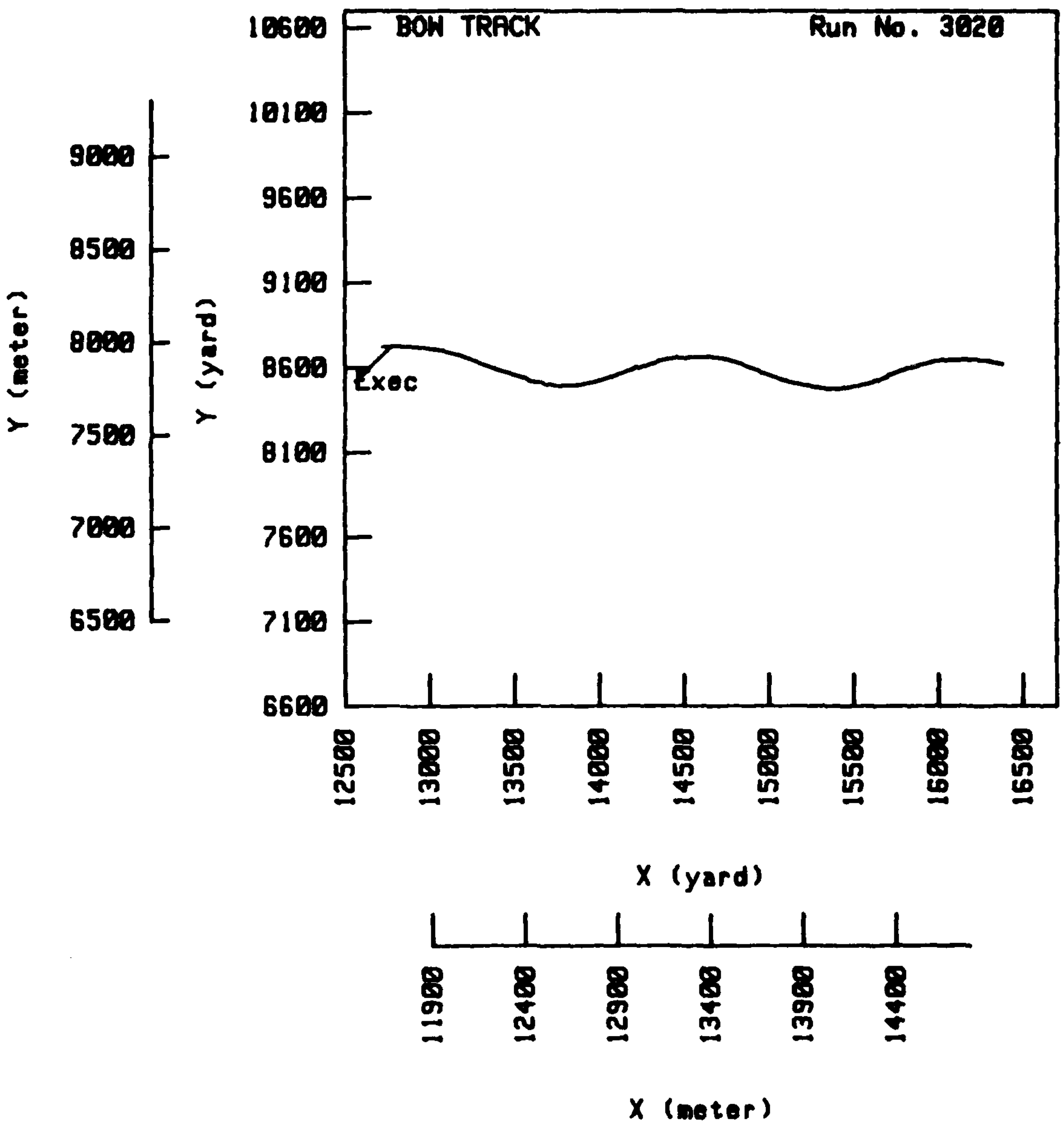


Figure 73 - Position Plot for Full Ahead, 20/20 Degrees Overshoot Maneuver (Run 3020)

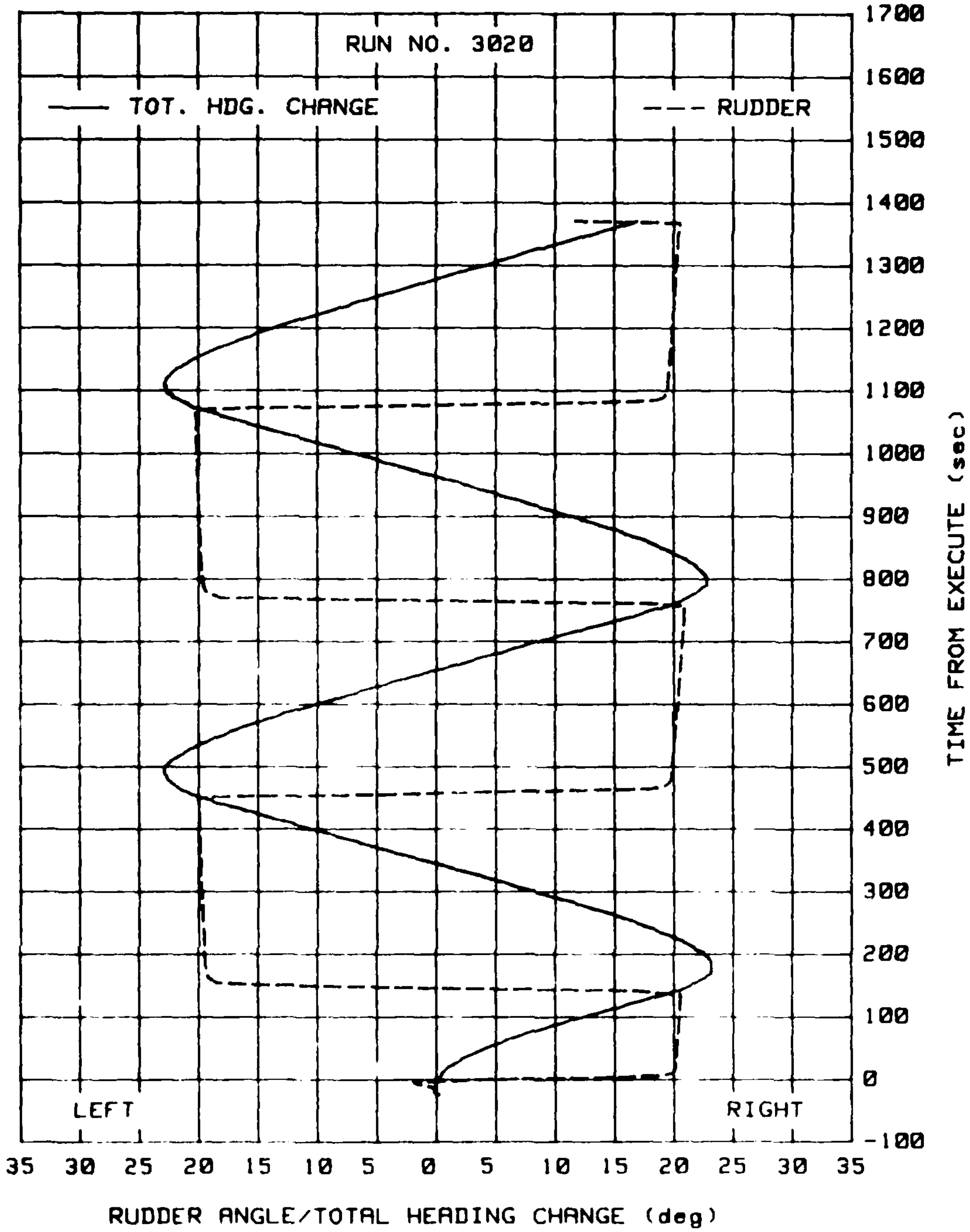


Figure 74 - Rudder and Heading Changes during Full Ahead, 20/20 Degrees Overshoot Maneuver (Run 3020)

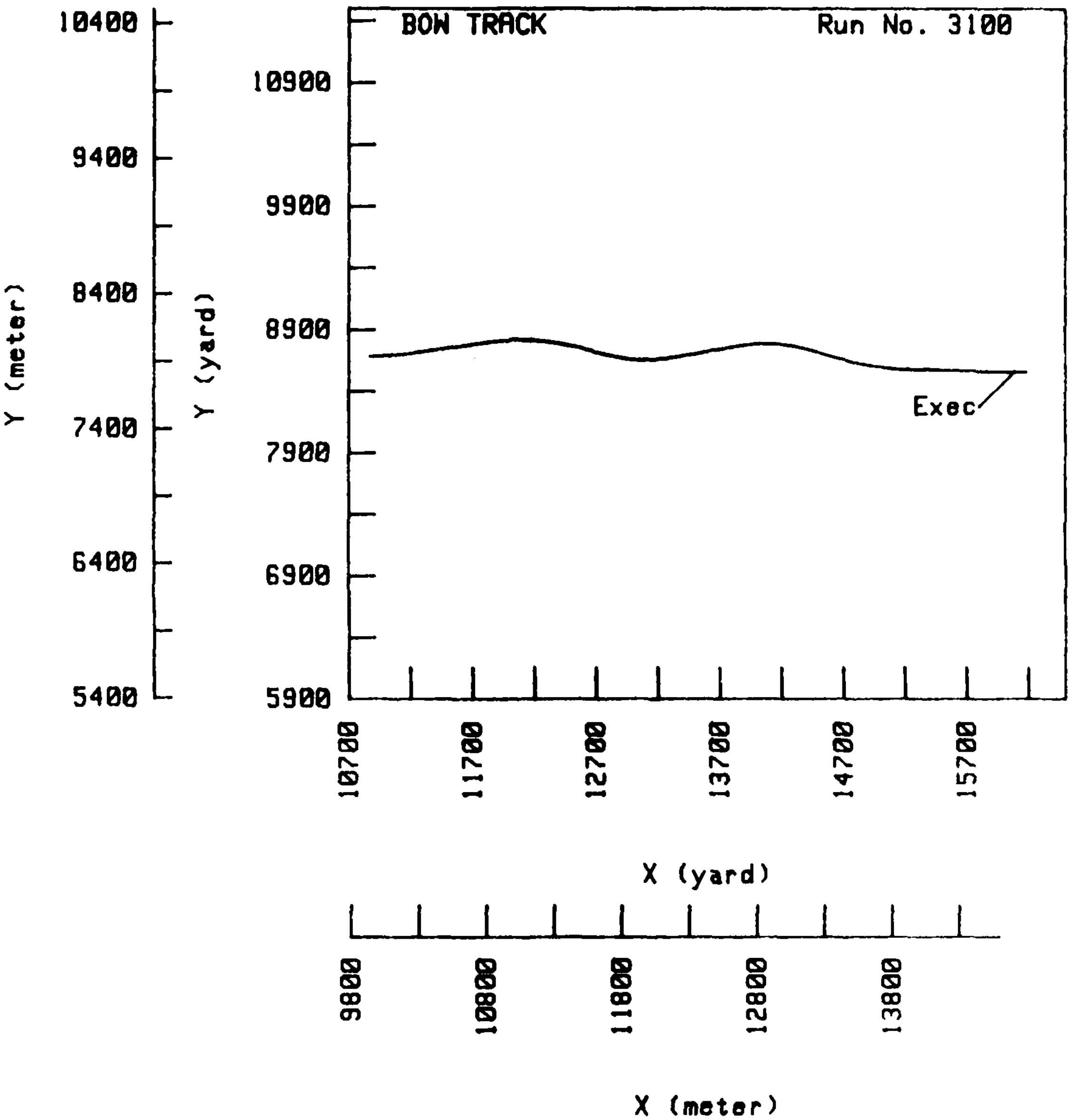


Figure 75 - Position Plot for Full Astern, 10/10 Degrees Overshoot Maneuver (Run 3100)

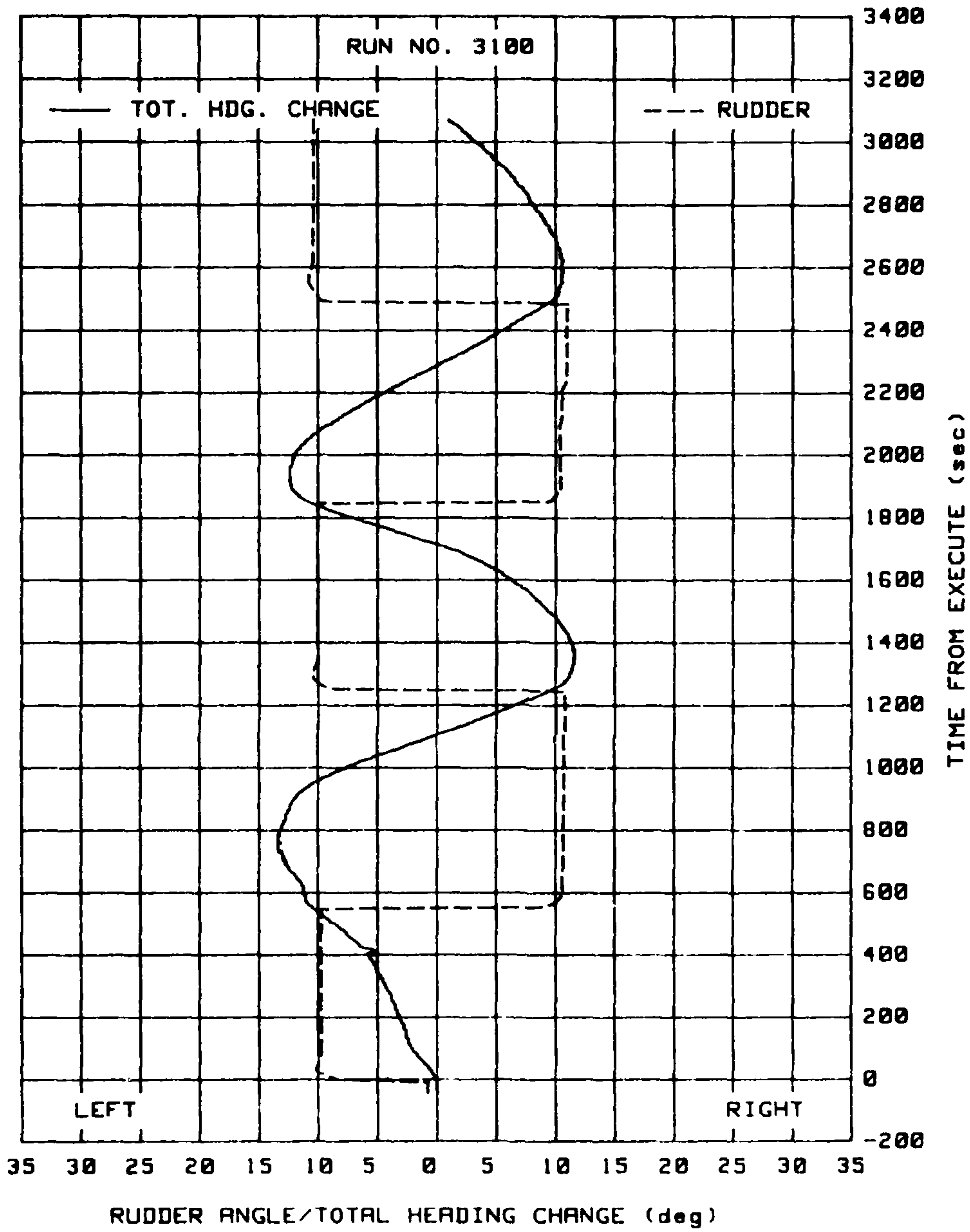


Figure 76 - Rudder and Heading Changes during Full Astern, 10/10 Degrees Overshoot Maneuver (Run 3100)

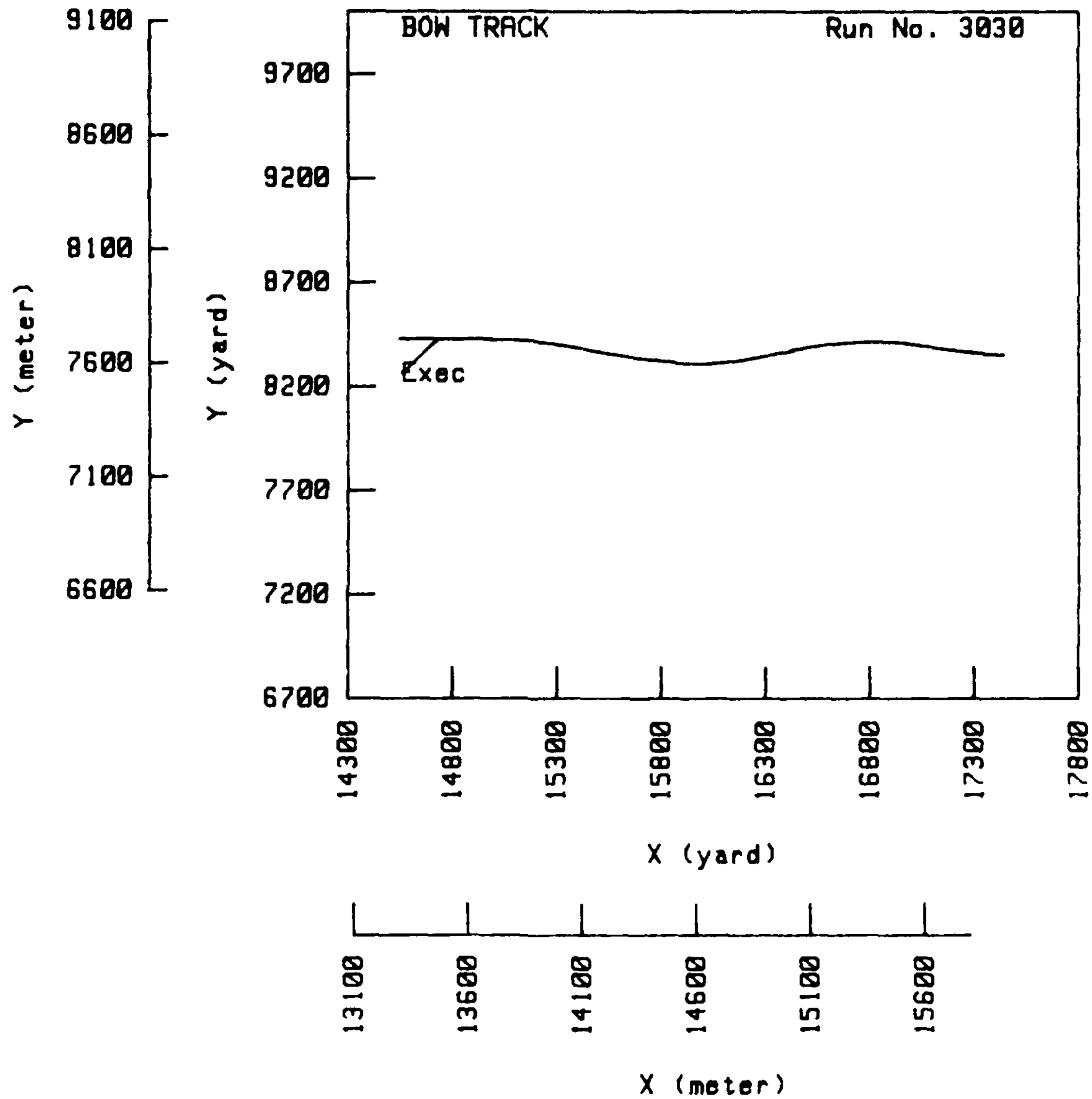


Figure 77 - Position Plot for Full Ahead to Half Ahead, 10/10 Degrees Overshoot Maneuver (Run 3030)

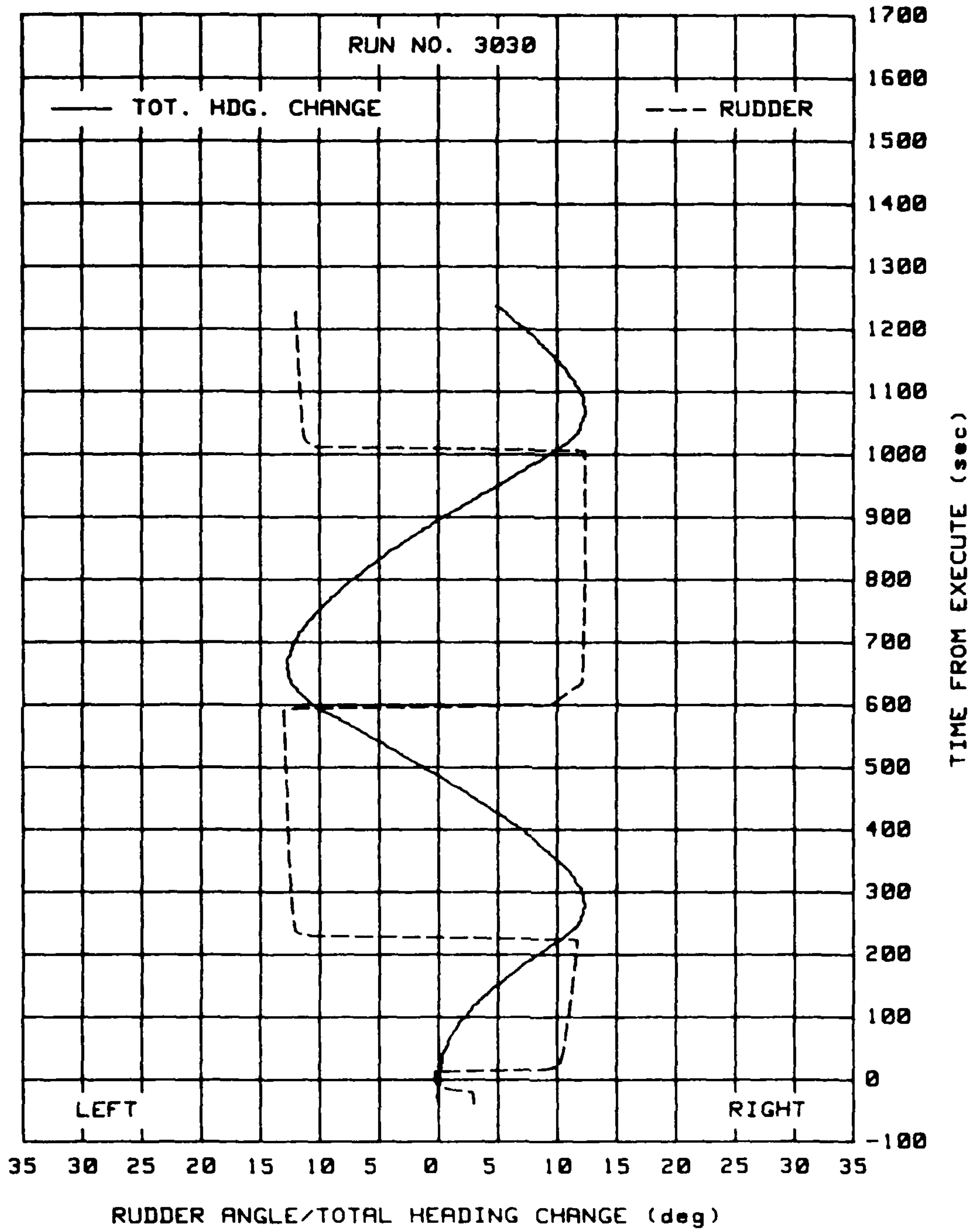


Figure 78 - Rudder and Heading Changes during Full Ahead to Half Ahead, 10/10 Degrees Overshoot Maneuver (Run 3030)

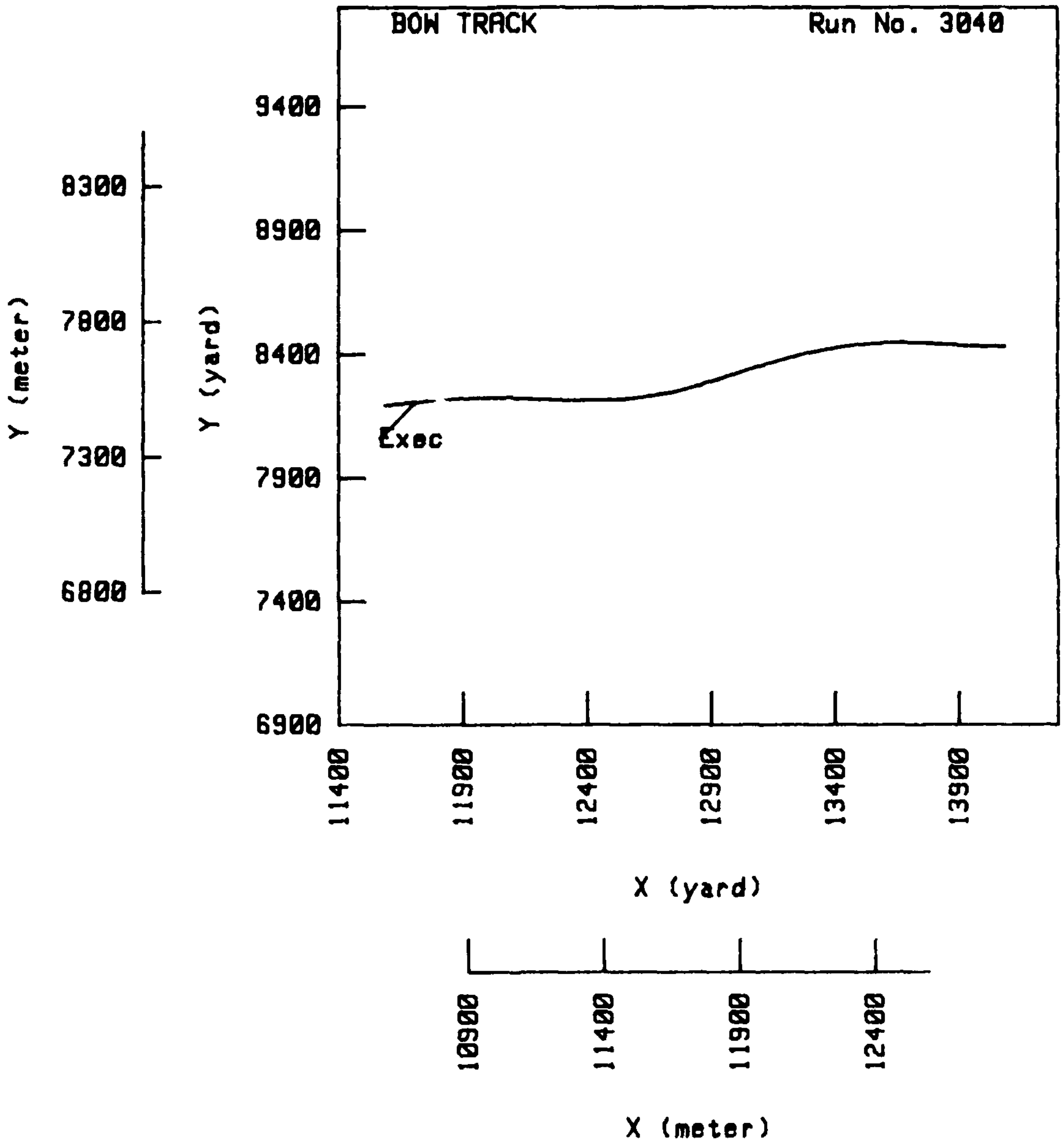


Figure 79 - Position Plot for Half Ahead to Full Ahead, 10/10 Degrees Overshoot Maneuver (Run 3040)

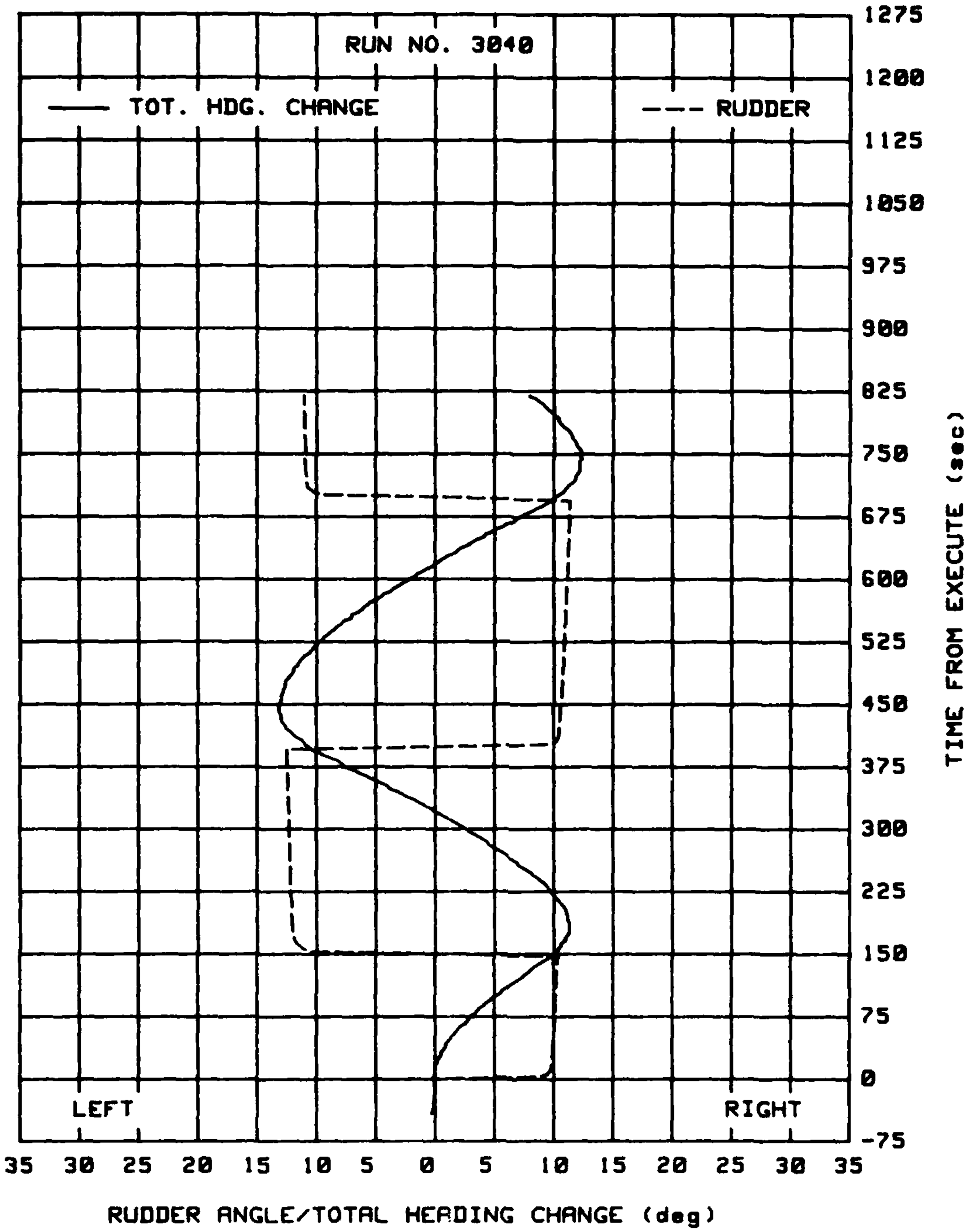


Figure 80 - Rudder and Heading Changes during Half Ahead to Full Ahead, 10/10 Degrees Overshoot Maneuver (Run 3040)

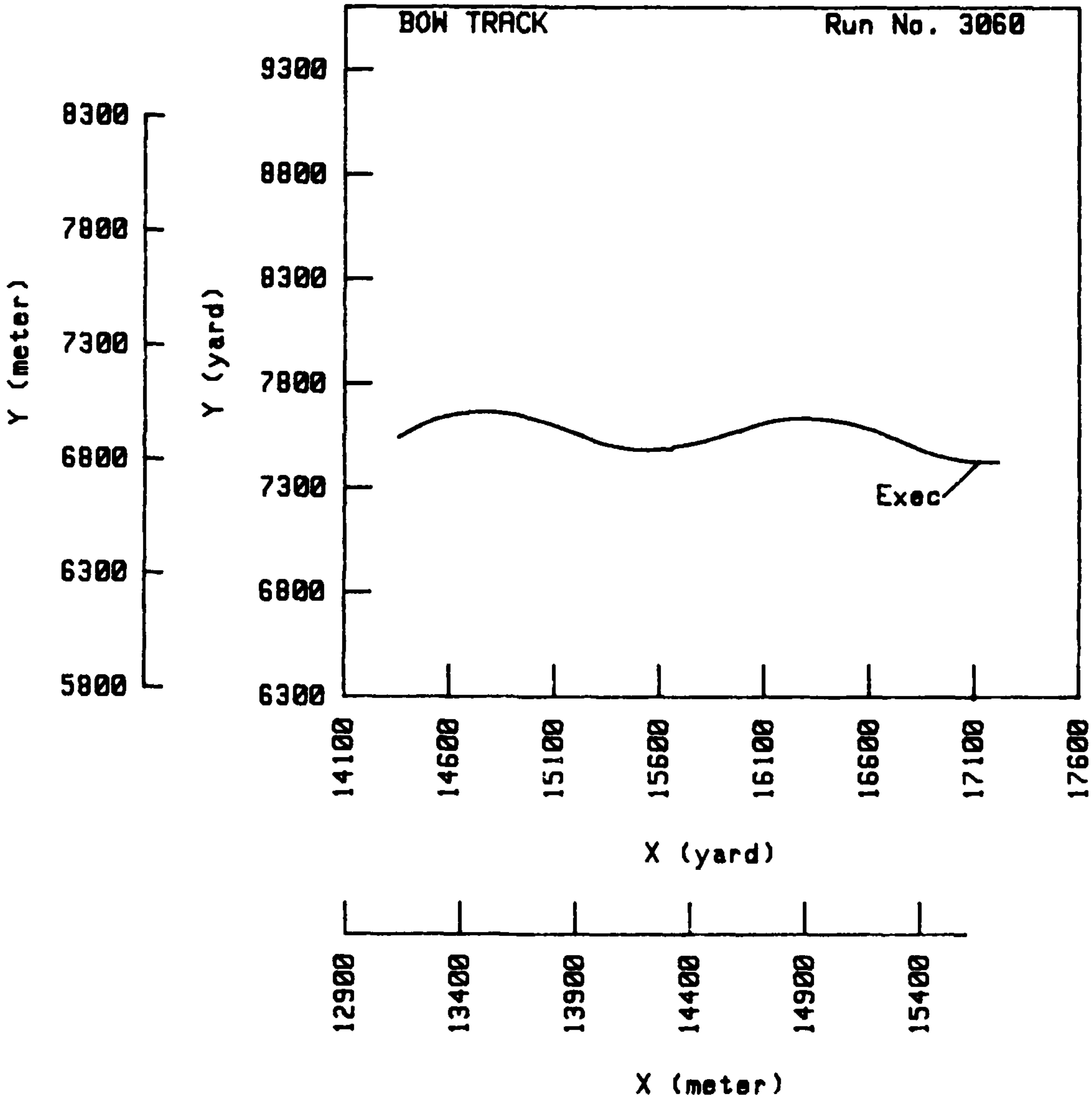


Figure 81 - Position Plot for Half Ahead to Full Ahead, 20/20 Degrees Overshoot Maneuver (Run 3060)

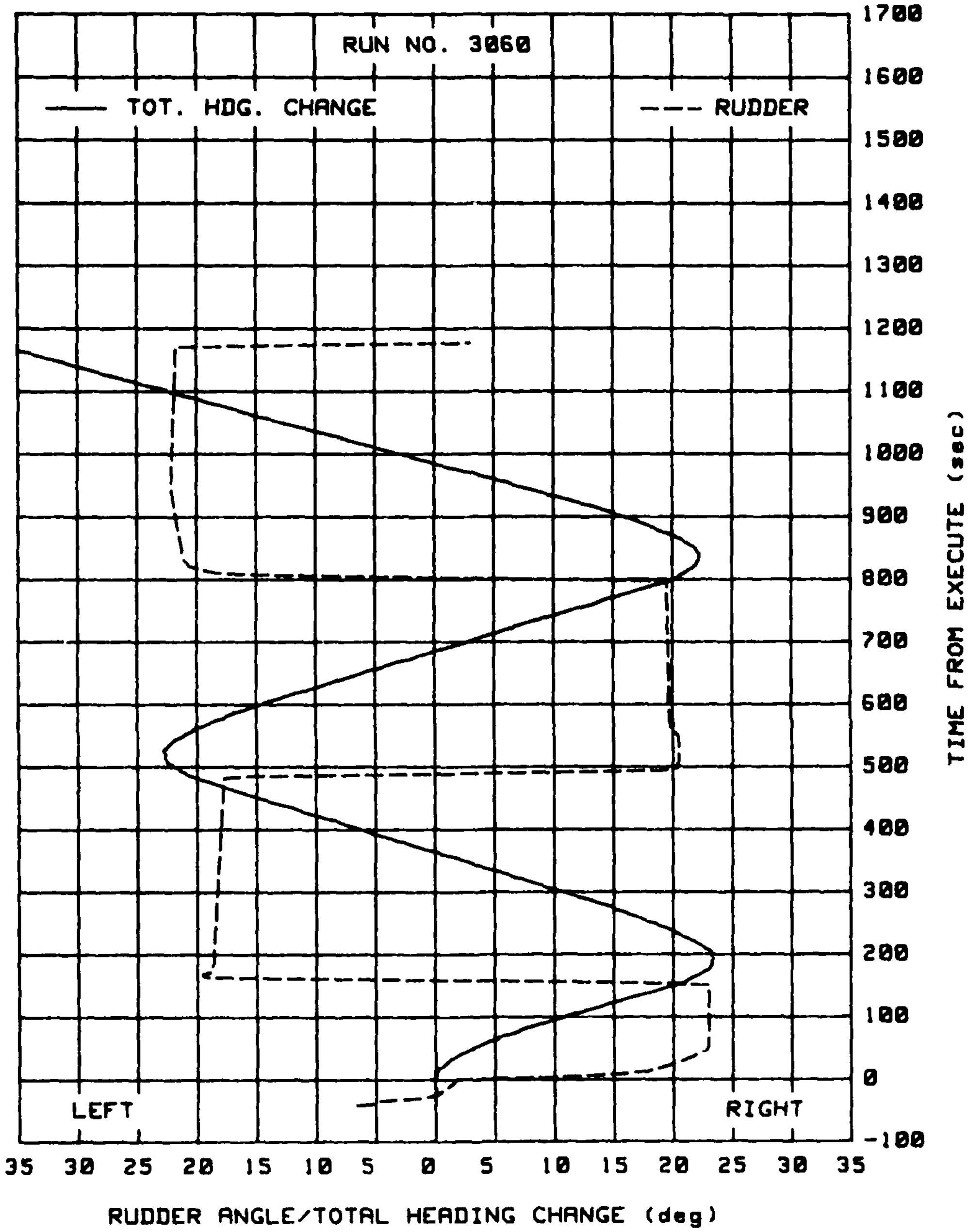


Figure 82 - Rudder and Heading Changes during Half Ahead to Full Ahead, 20/20 Degrees Overshoot Maneuver (Run 3060)

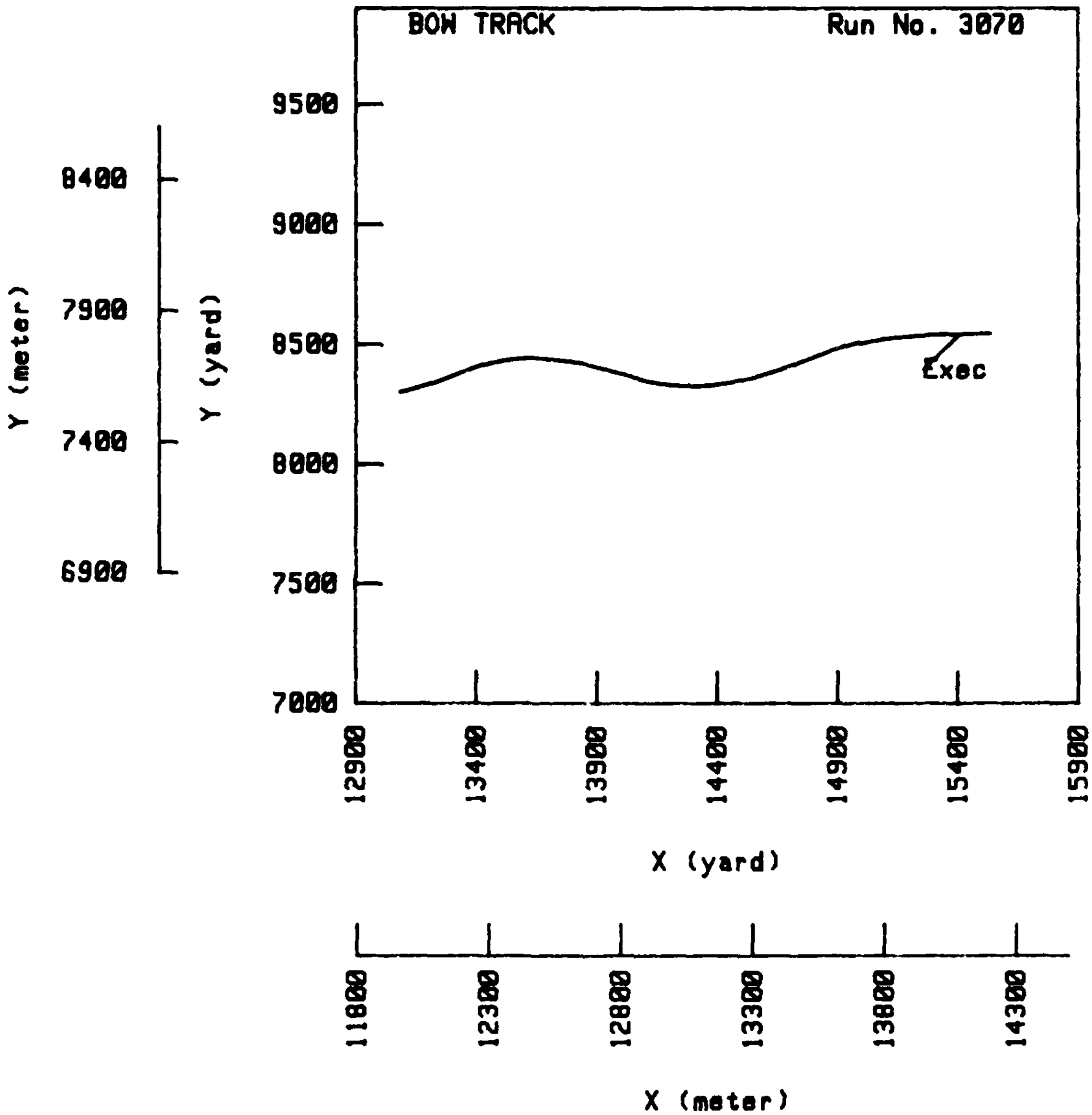


Figure 83 - Position Plot for Full Ahead to Half Ahead, 20/20 Degrees Overshoot (Run 3070)

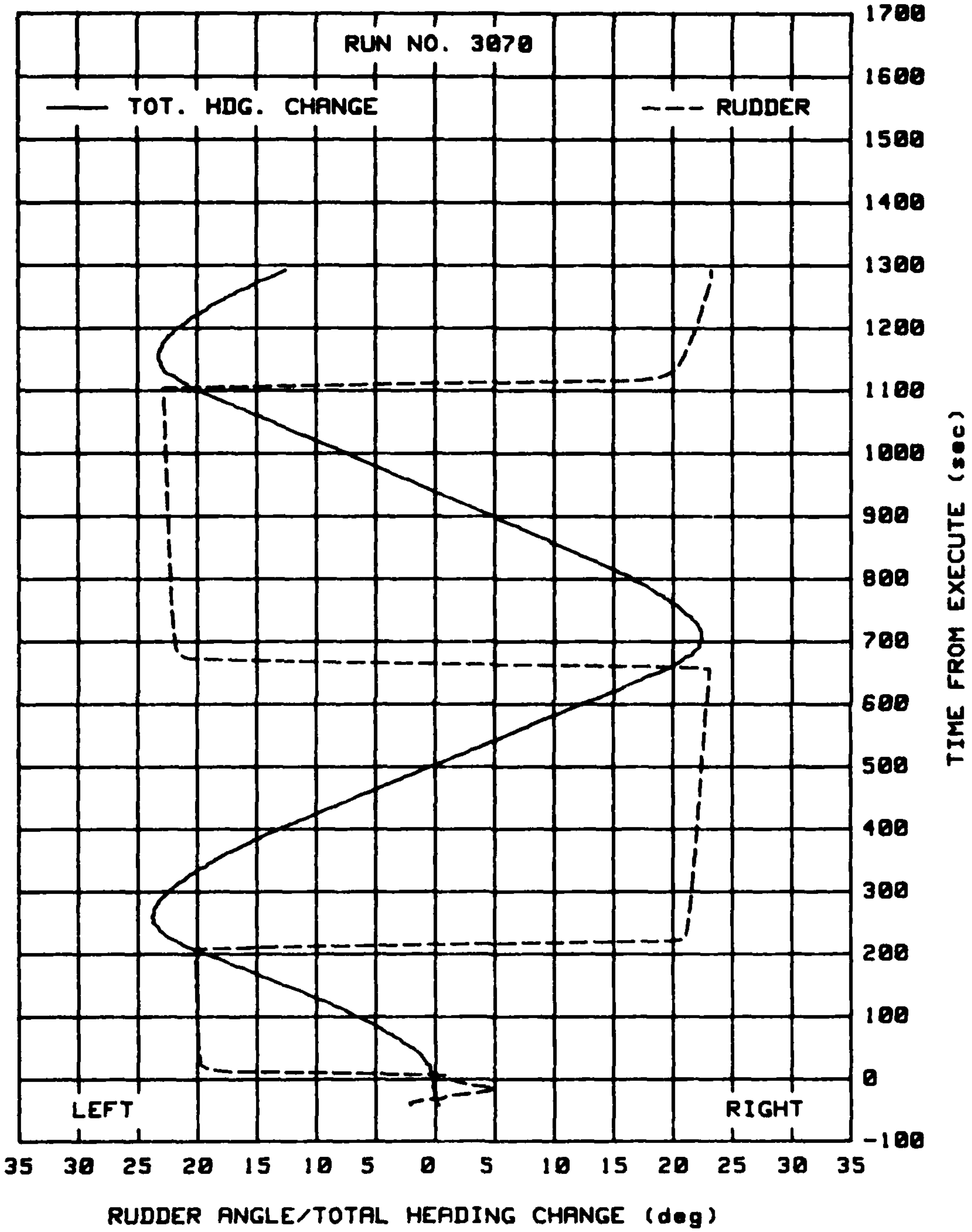


Figure 84 - Rudder and Heading Changes during Full Ahead to Half Ahead, 20/20 Degrees Overshoot (Run 3070)

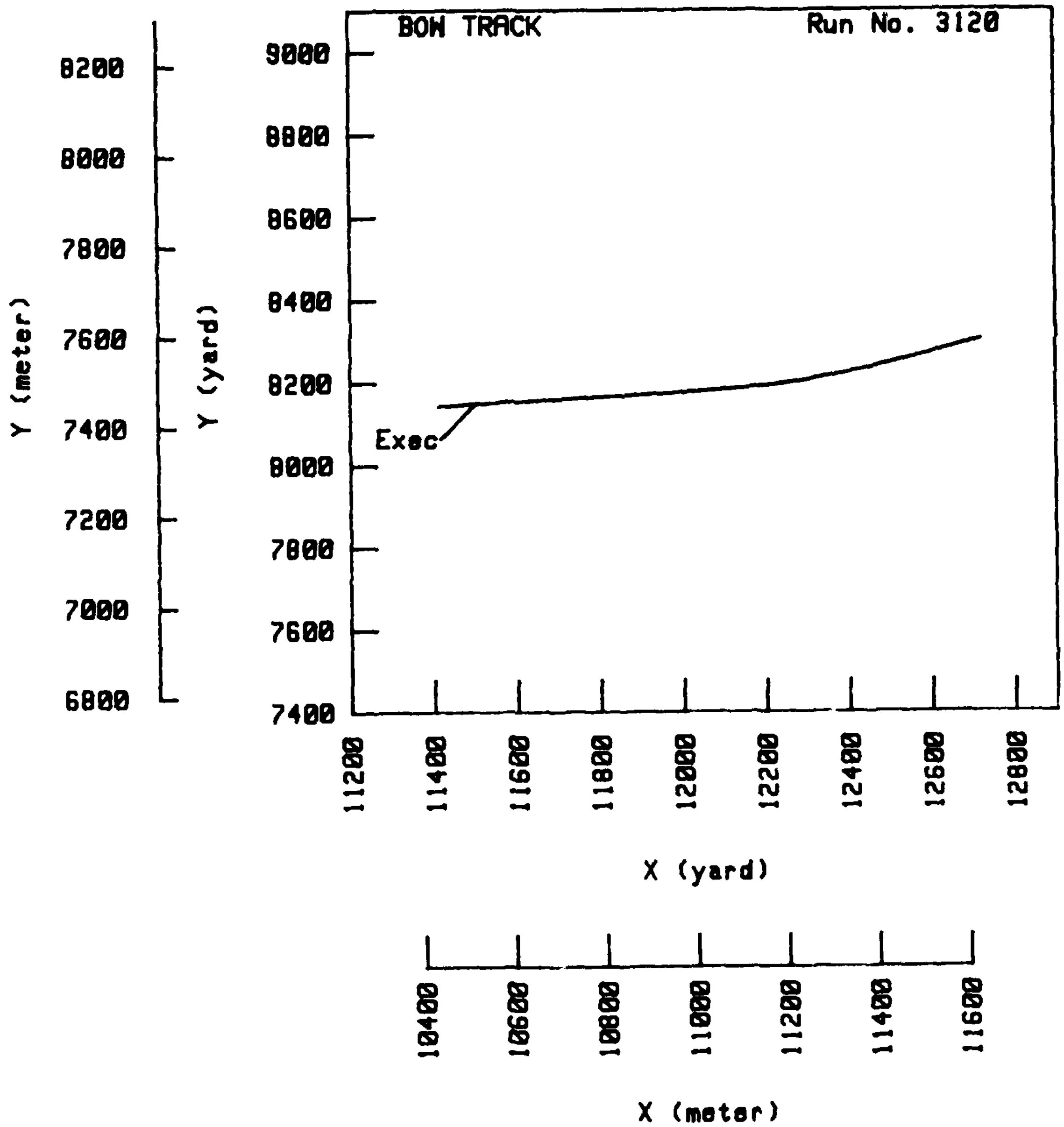


Figure 85 - Position Plot for Full Astern to Half Astern, 10/10 Degrees Overshoot Maneuver (Run 3120)

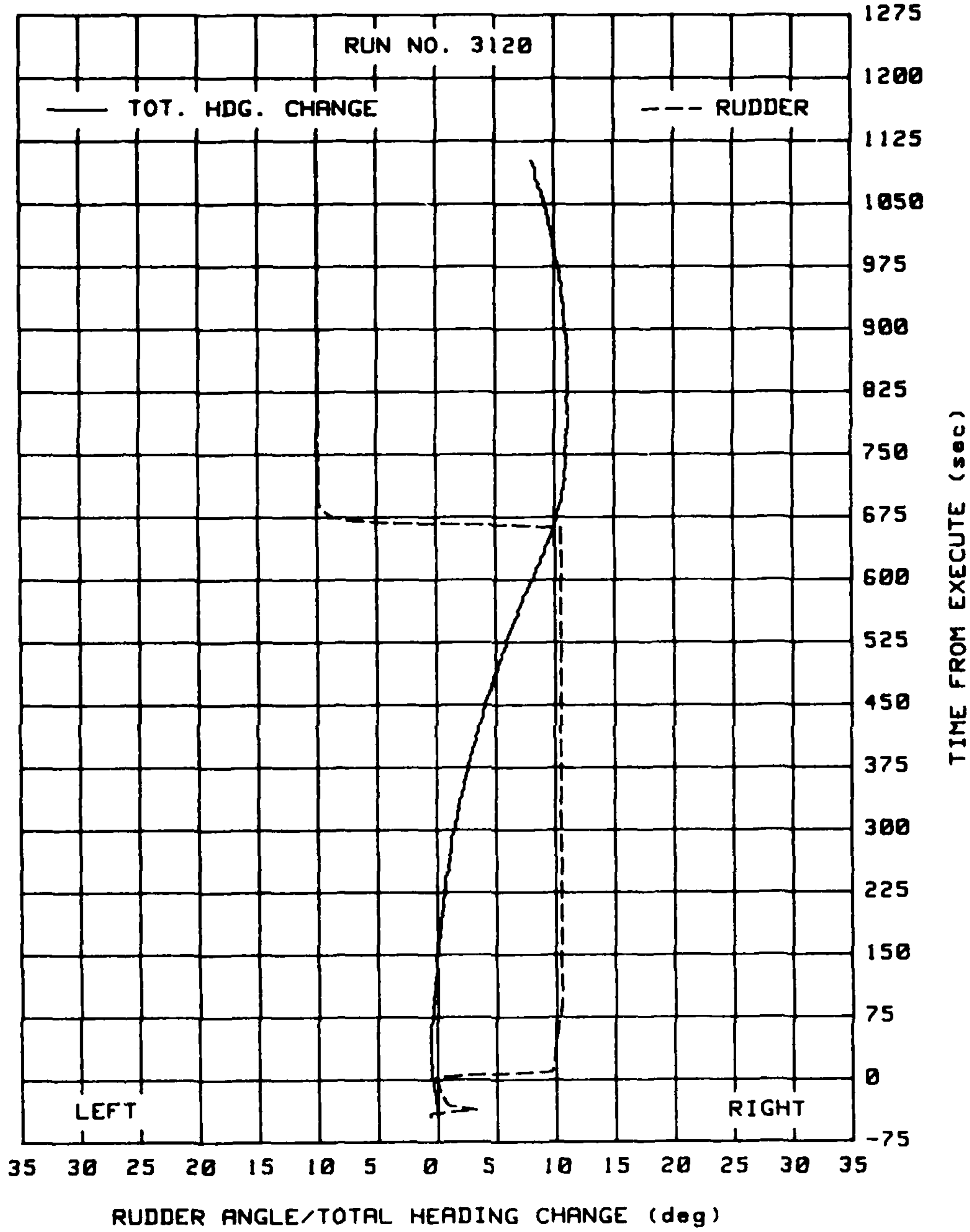


Figure 86 - Rudder and Heading Changes during Full Astern to Half Astern, 10/10 Degrees Overshoot Maneuver (Run 3120)

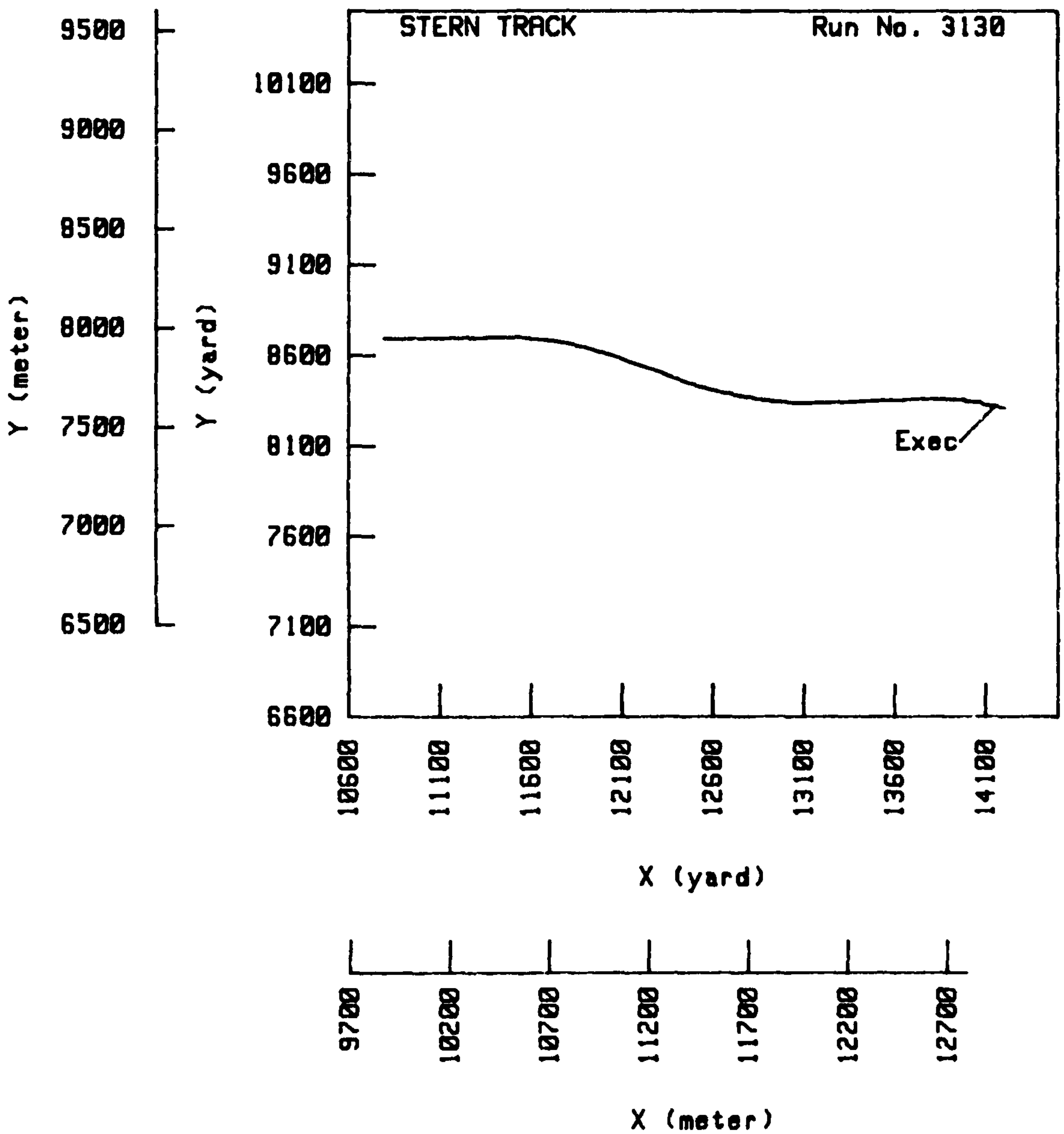


Figure 87 - Position Plot for Half Astern to Full Astern, 10/10 Degrees Overshoot Maneuver (Run 3130)

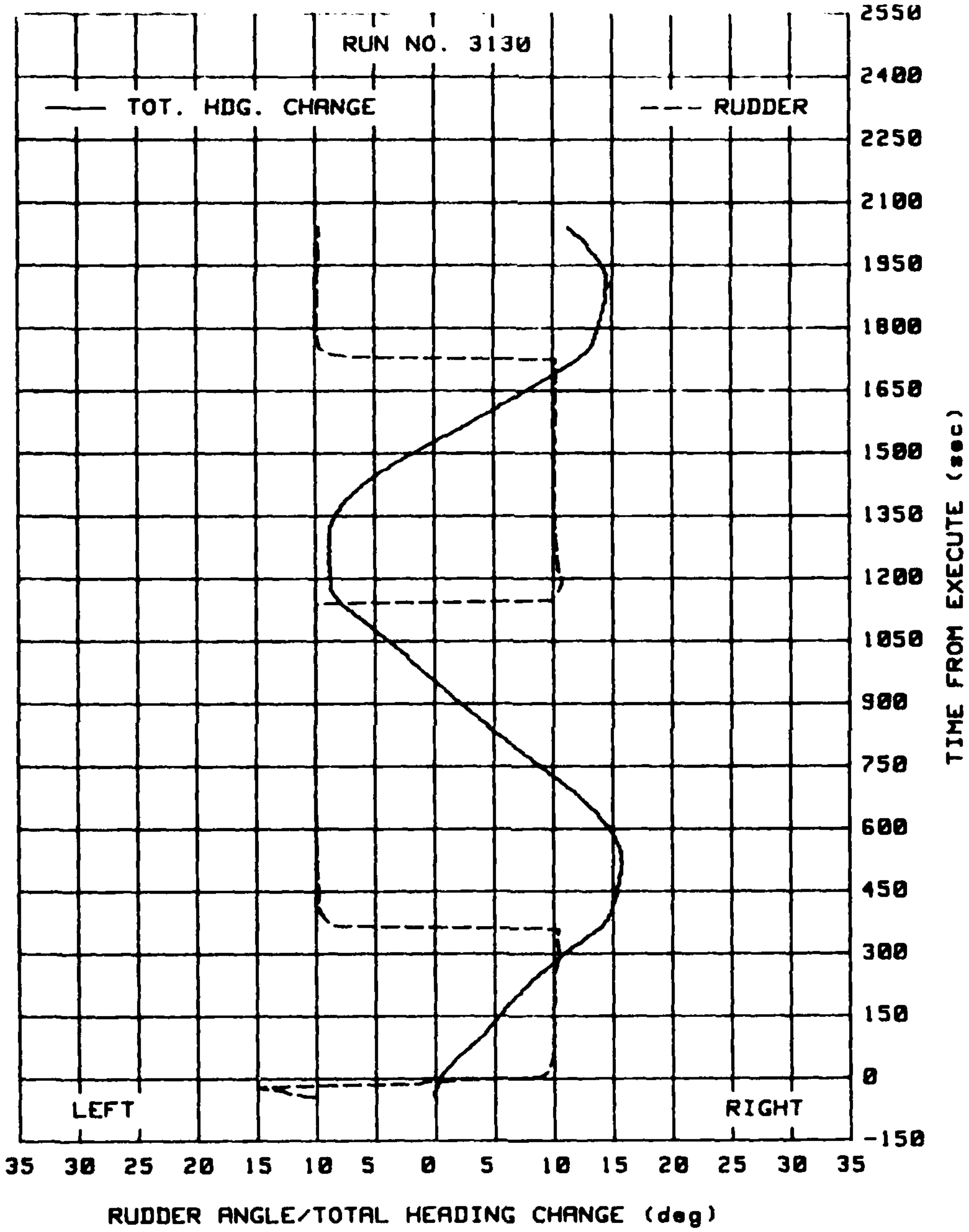


Figure 88 - Rudder and Heading Changes during Half Astern to Full Astern, 10/10 Overshoot Maneuver (Run 3130)

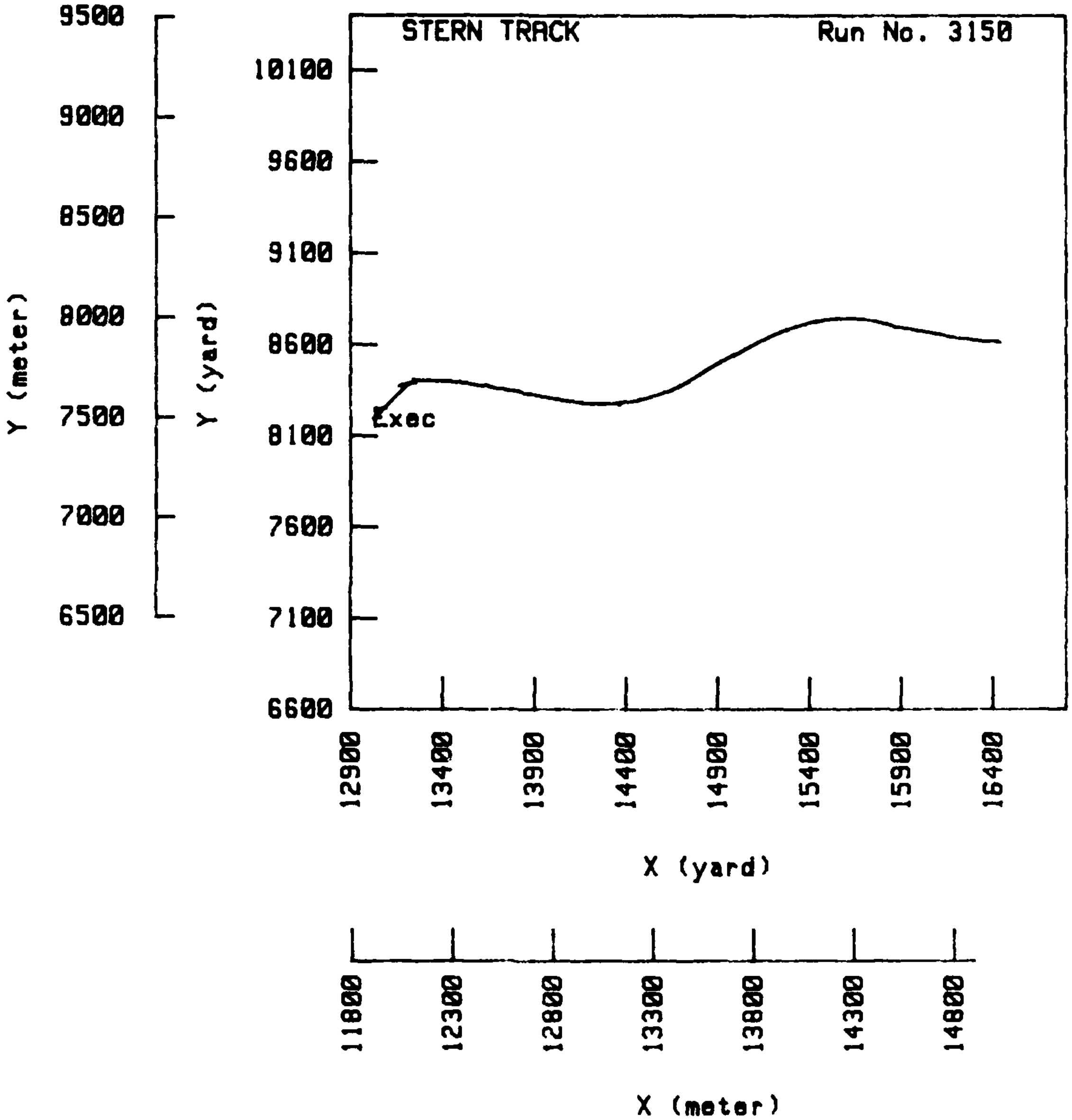


Figure 89 - Position Plot for Half Astern to Full Astern, 20/20 Degrees Overshoot Maneuver (Run 3150)

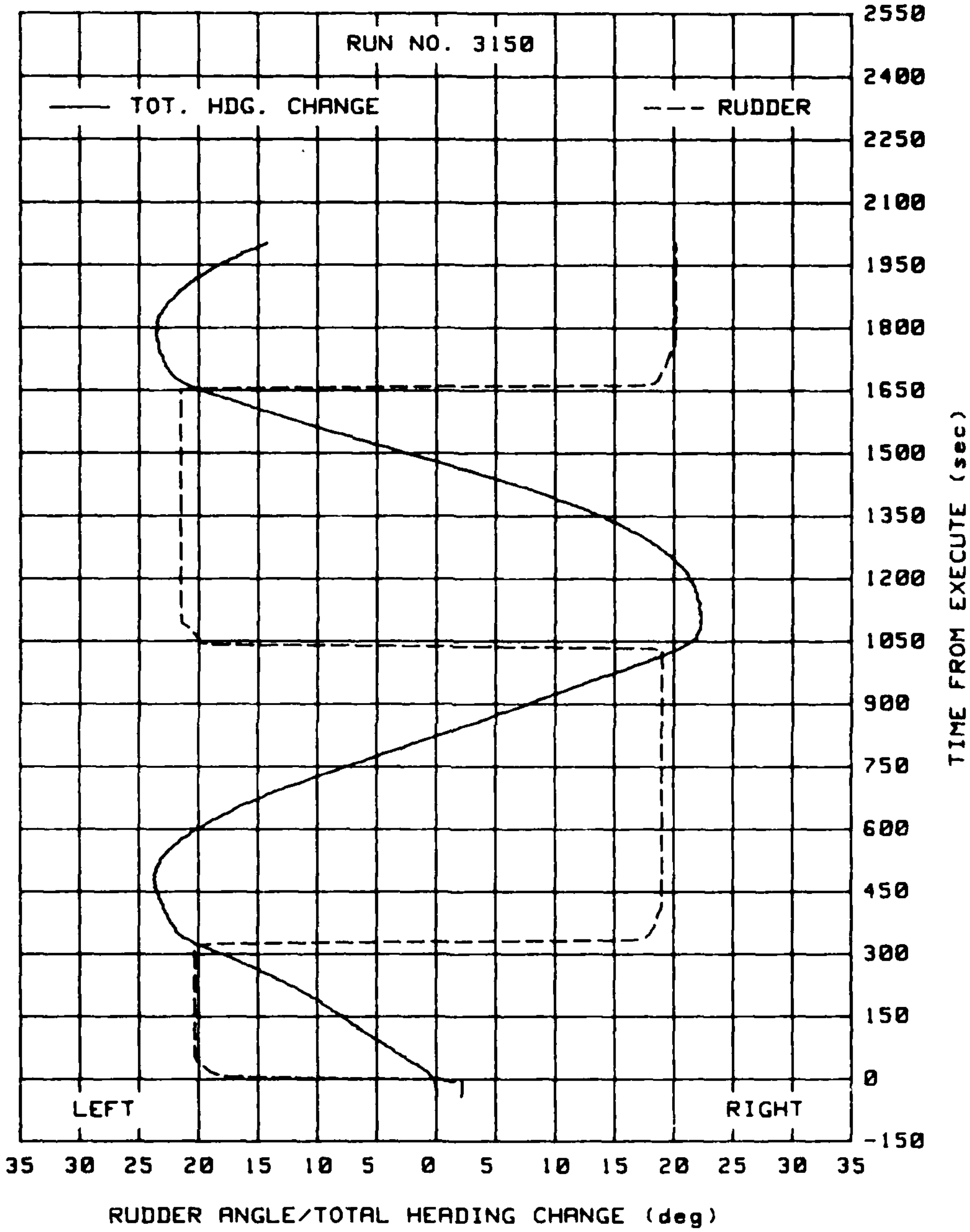


Figure 90 - Rudder and Heading Changes during Half Astern to Full Astern, 20/20 Degrees Overshoot Maneuver (Run 3150)

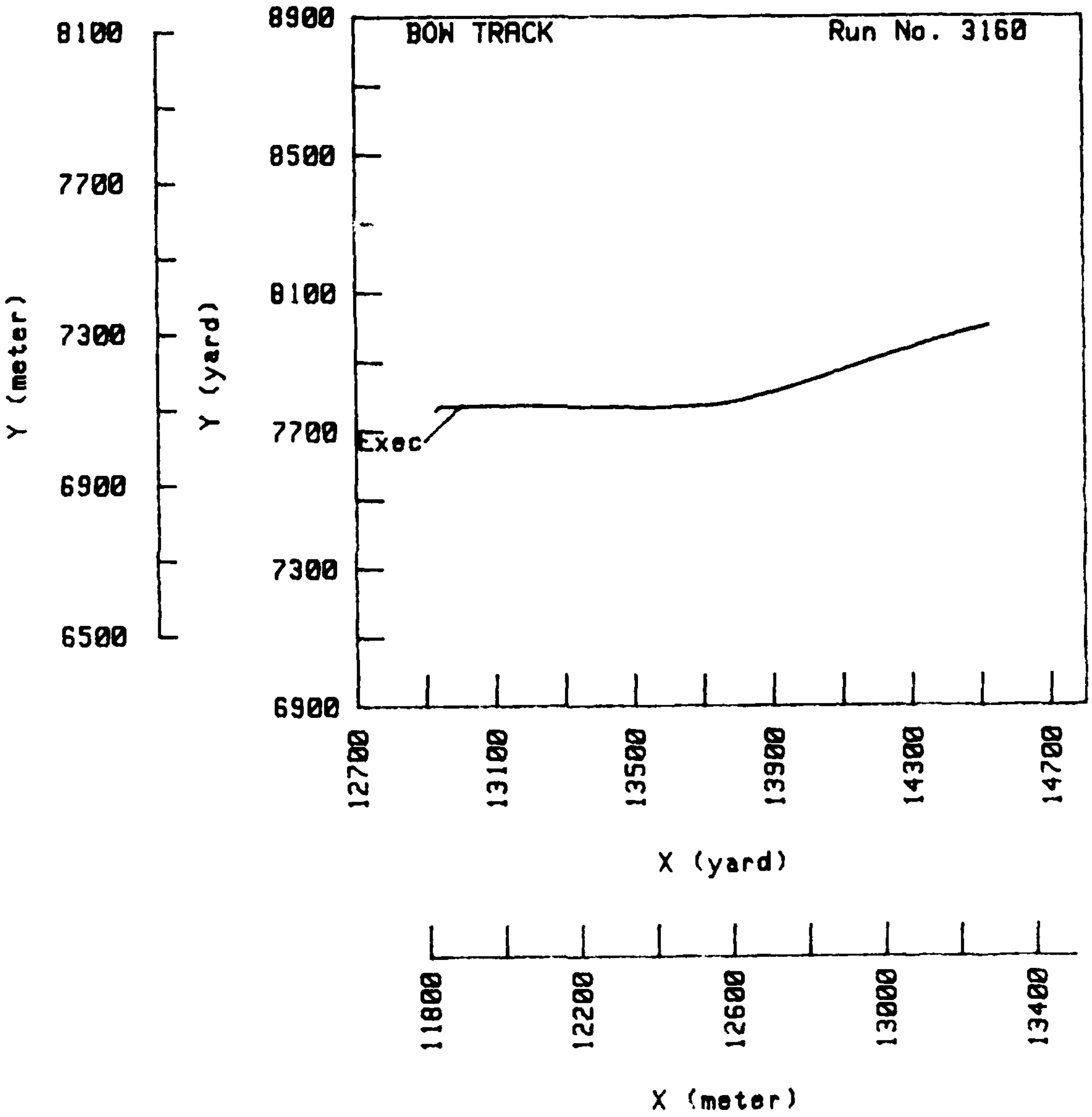


Figure 91 - Position Plot for Full Astern to Half Astern, 20/20 Degrees Overshoot Maneuver (Run 3160)

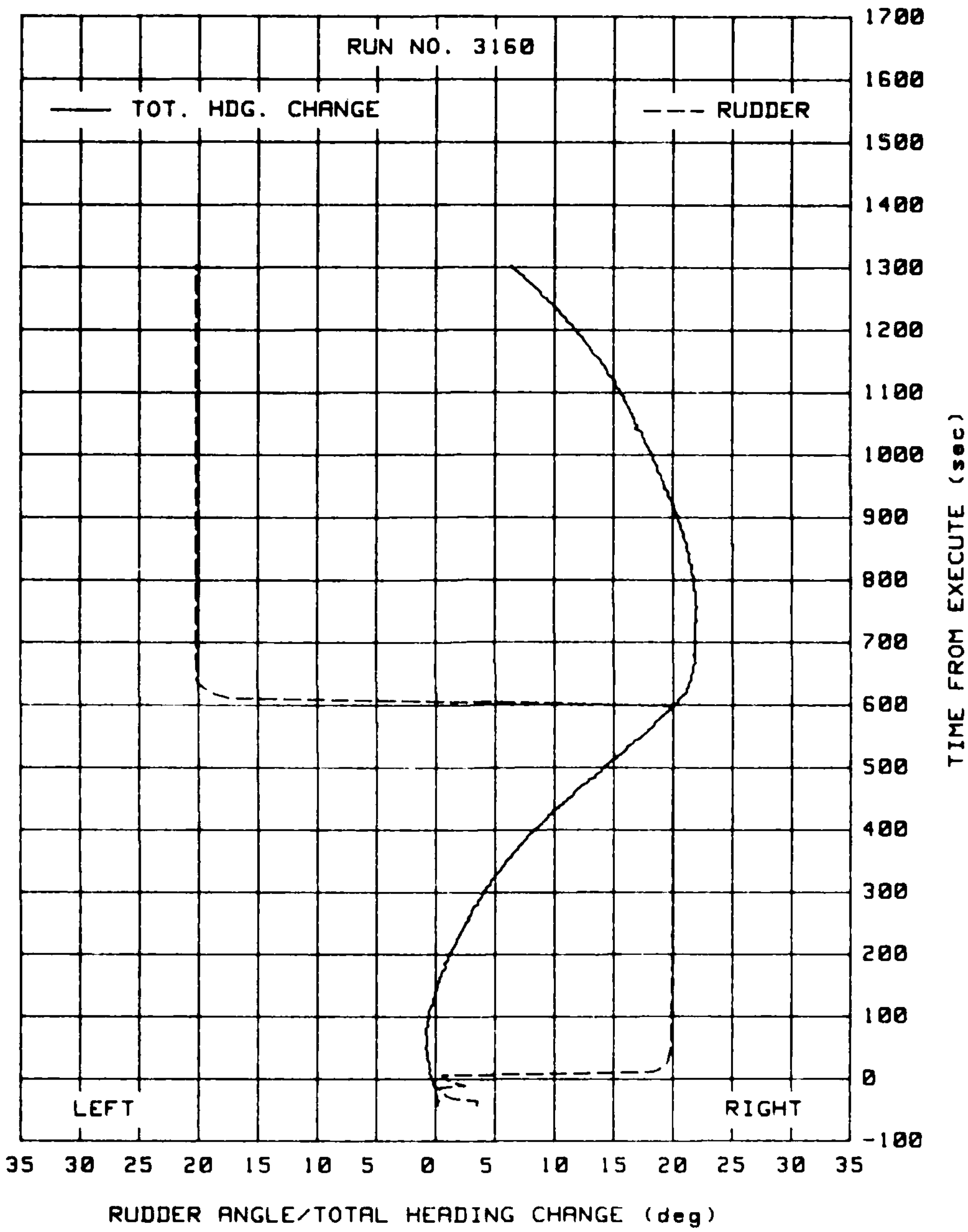


Figure 92 - Rudder and Heading Changes during Full Astern to Half Astern, 20/20 Degrees Overshoot Maneuver (Run 3160)

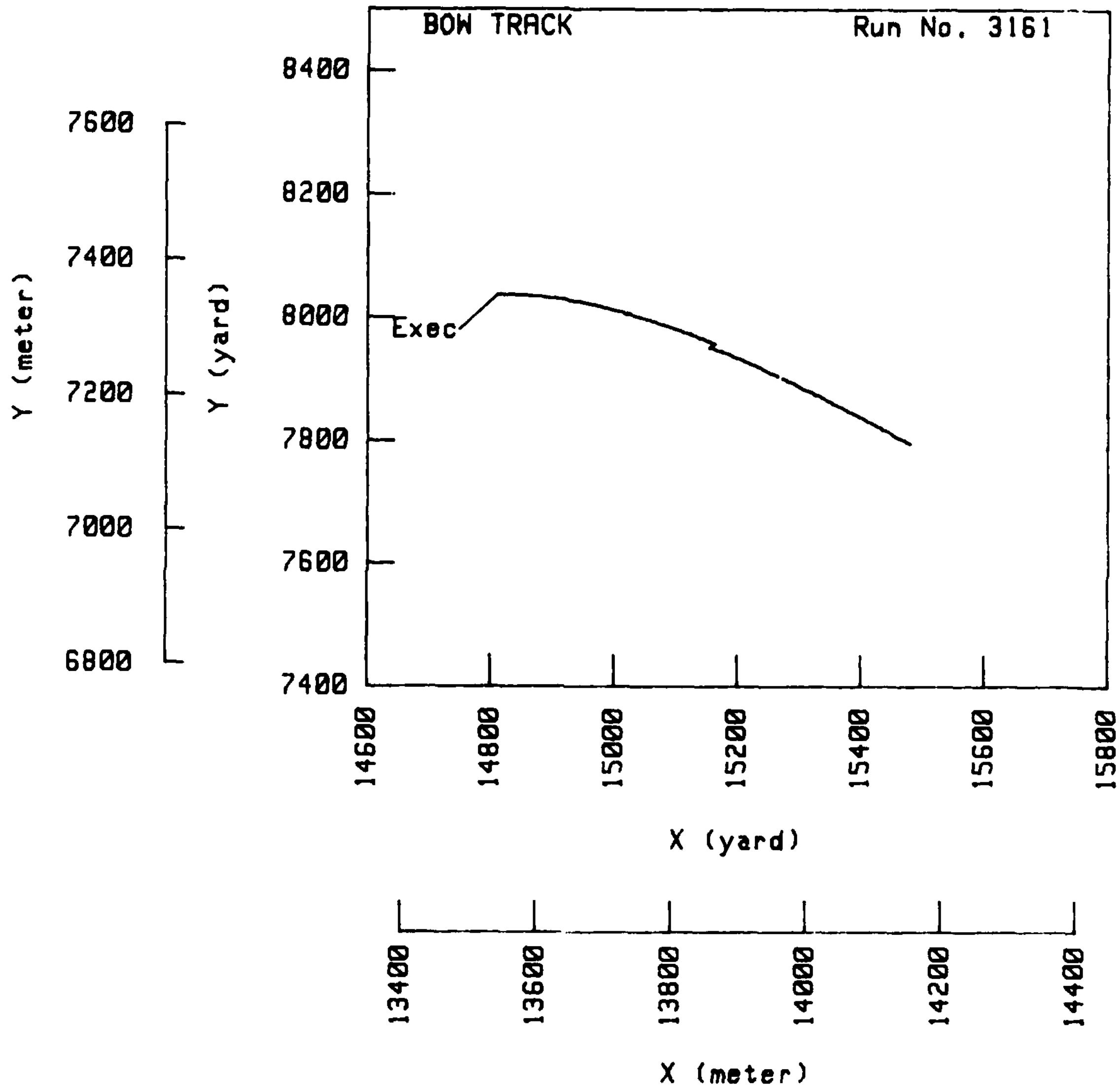


Figure 93 - Position Plot for Full Astern to Half Astern, 20/20 Degrees Overshoot Maneuver (Run 3161, Continuation of Run 3160)

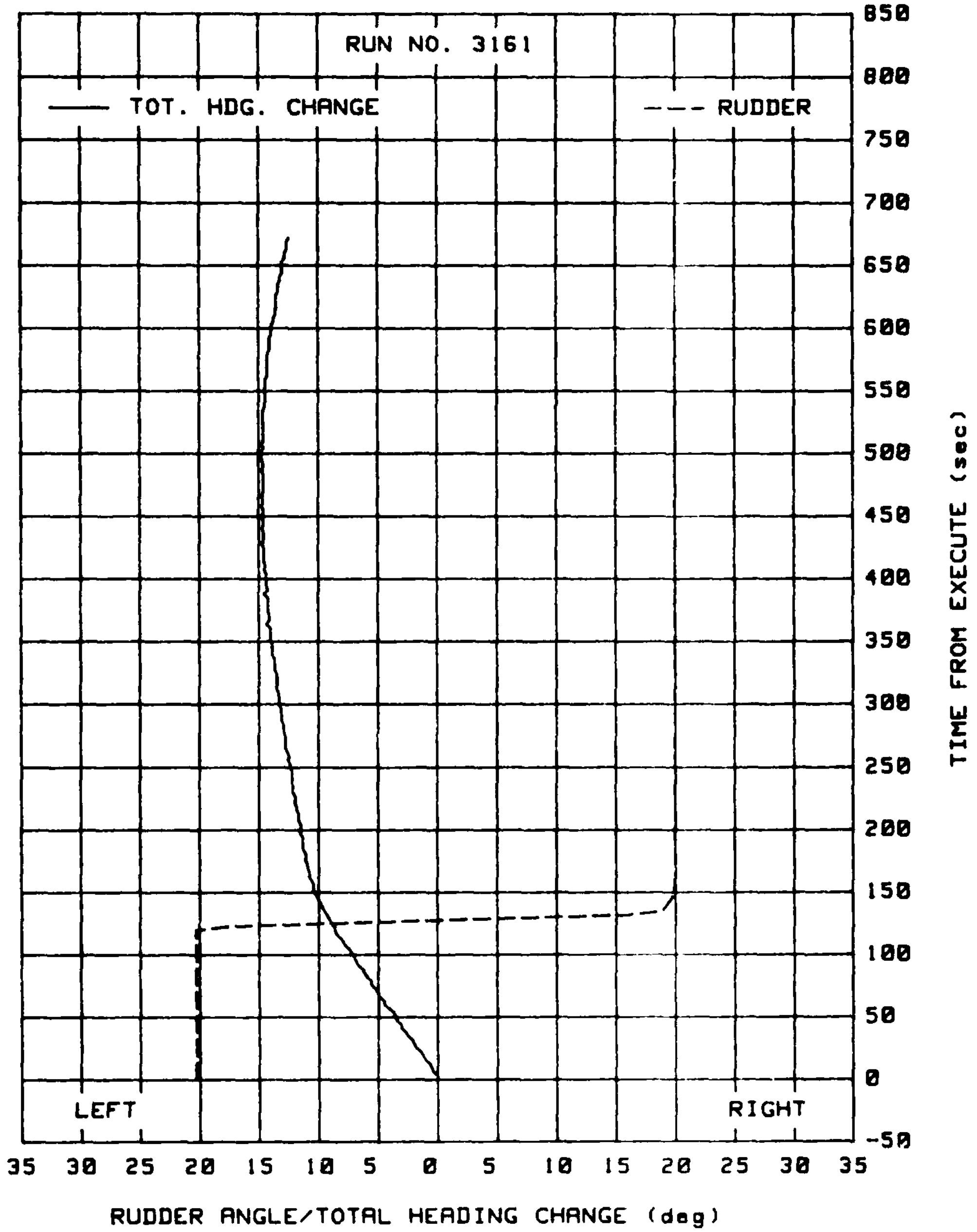


Figure 94 - Rudder and Heading Changes during Full Astern to Half Astern, 20/20 Degrees Overshoot Maneuver (Run 3161, Continuation of Run 3160)

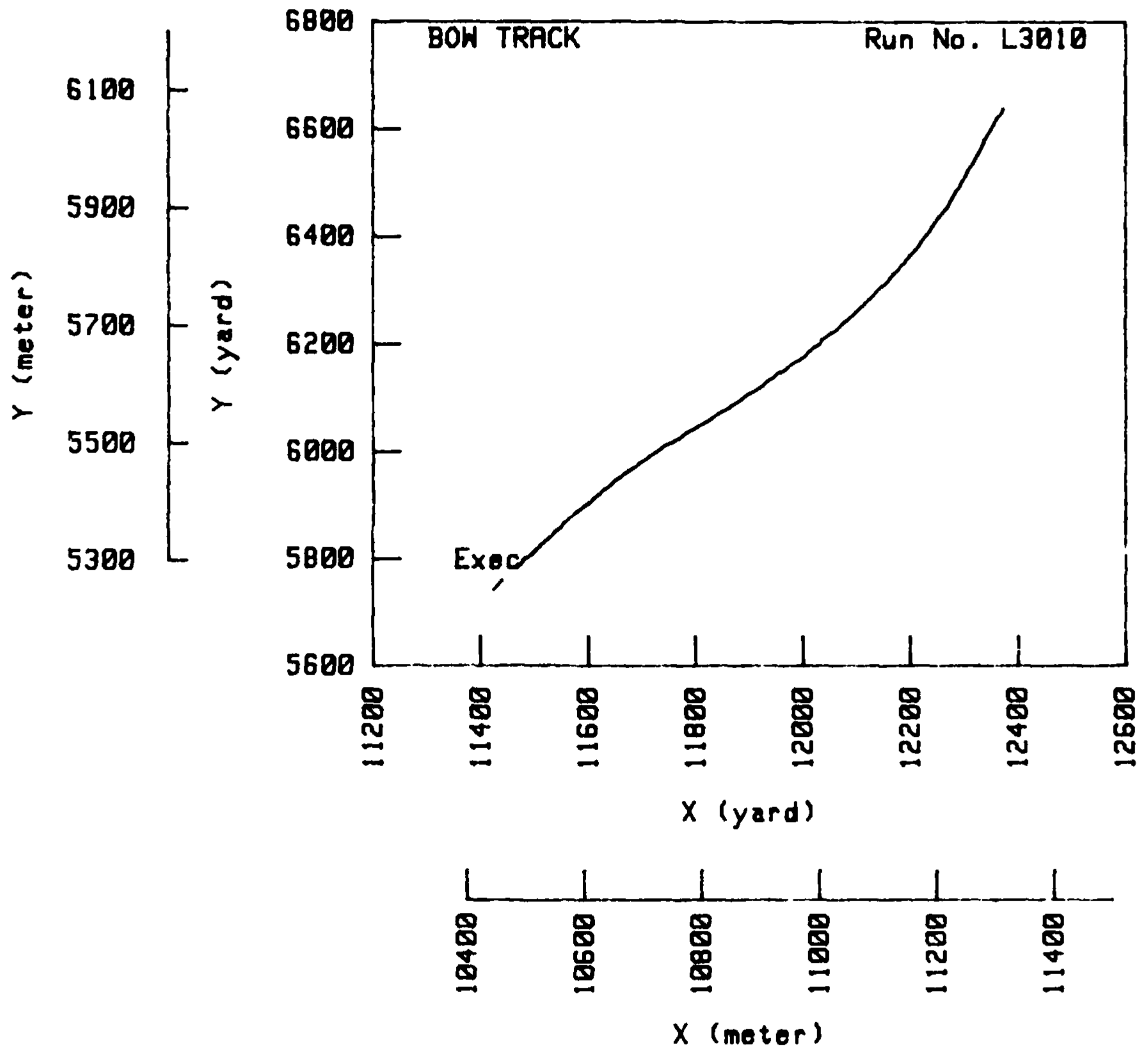


Figure 95 - Position Plot for Full Ahead, 10/10 Degrees Overshoot Maneuver (Run L3010)

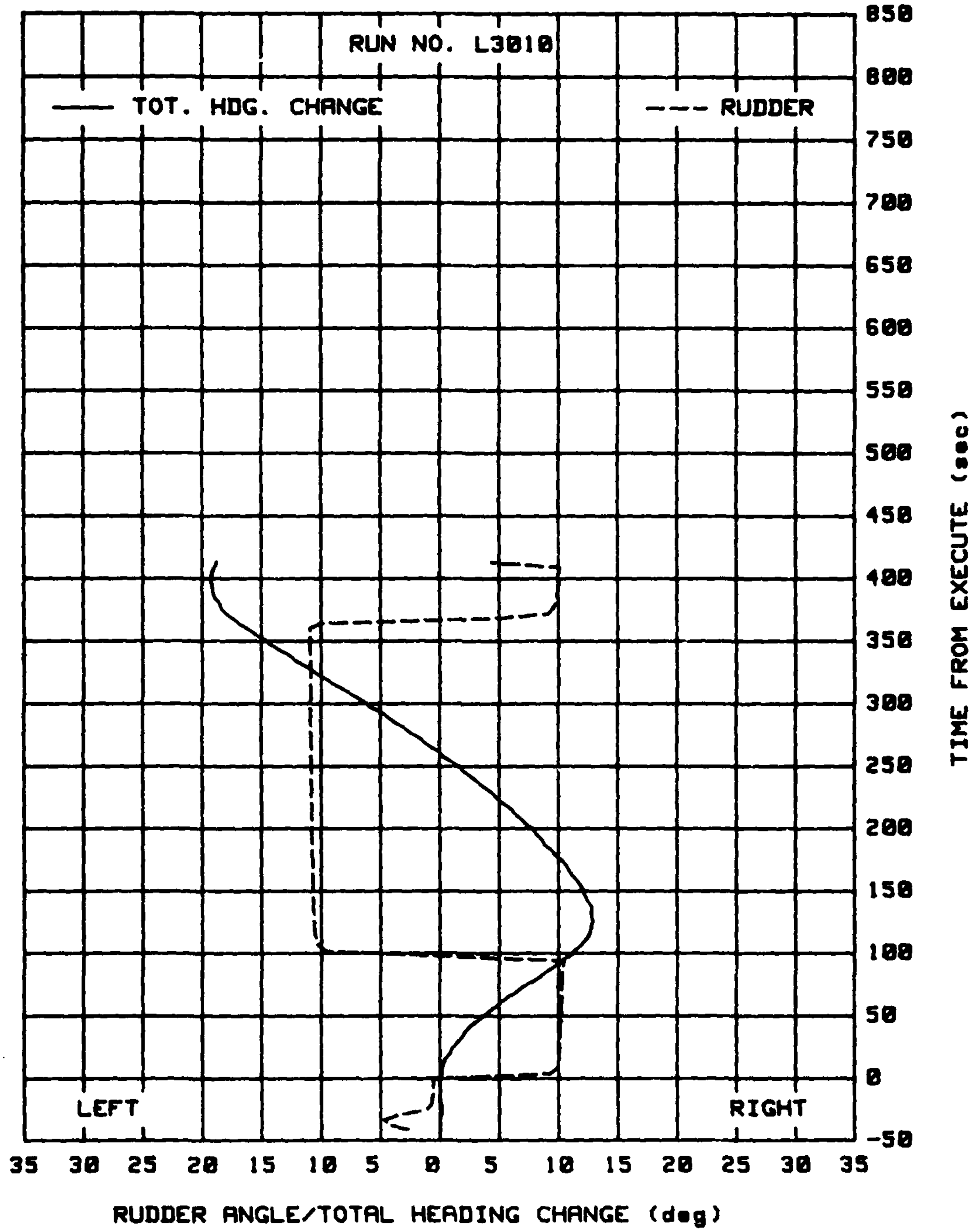


Figure 96 - Rudder and Heading Changes during Full Ahead, 10/10 Degrees Overshoot Maneuver (Run L3010)

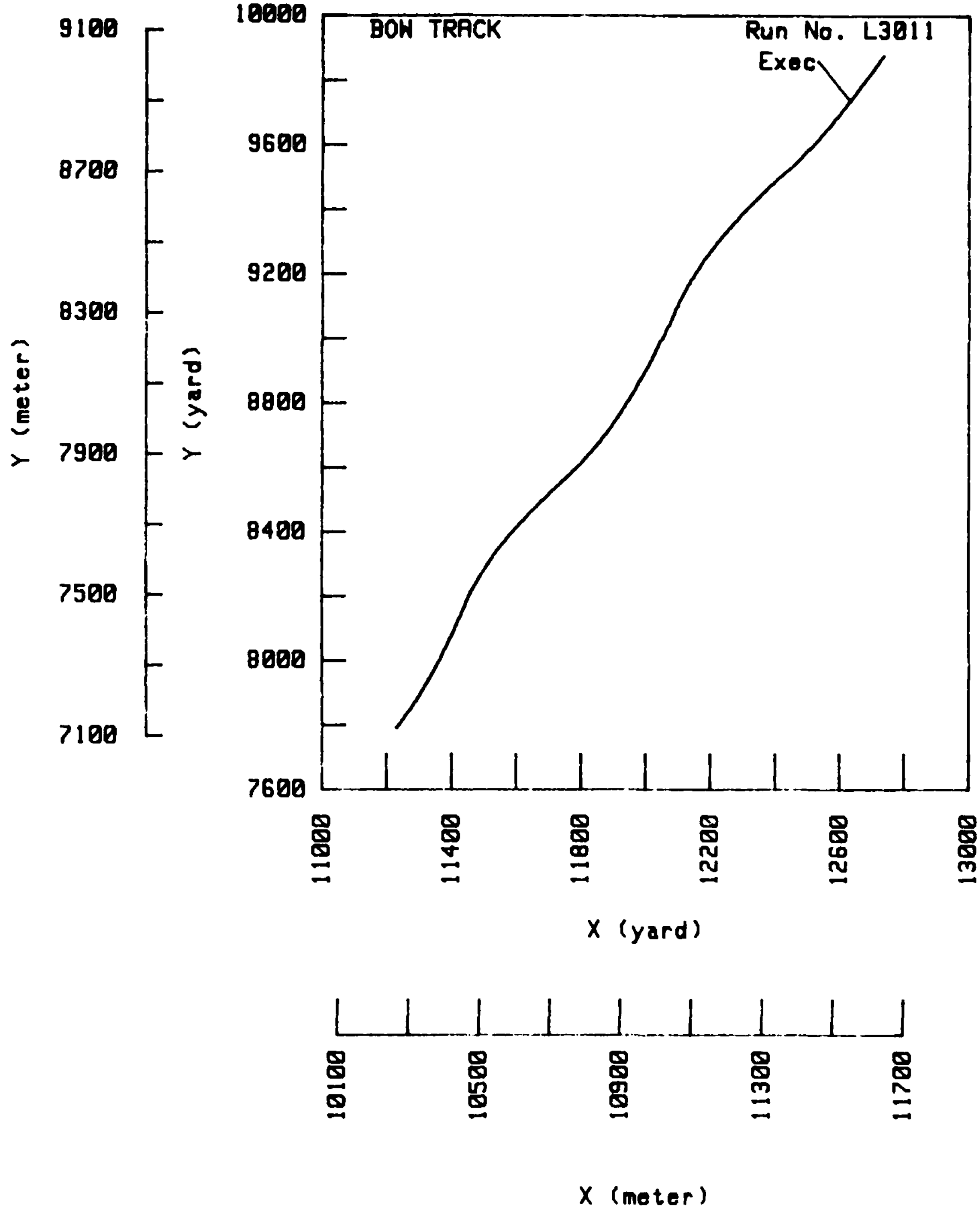


Figure 97 - Position Plot for Full Ahead, 10/10 Degrees Overshoot Maneuver (Run L3011)

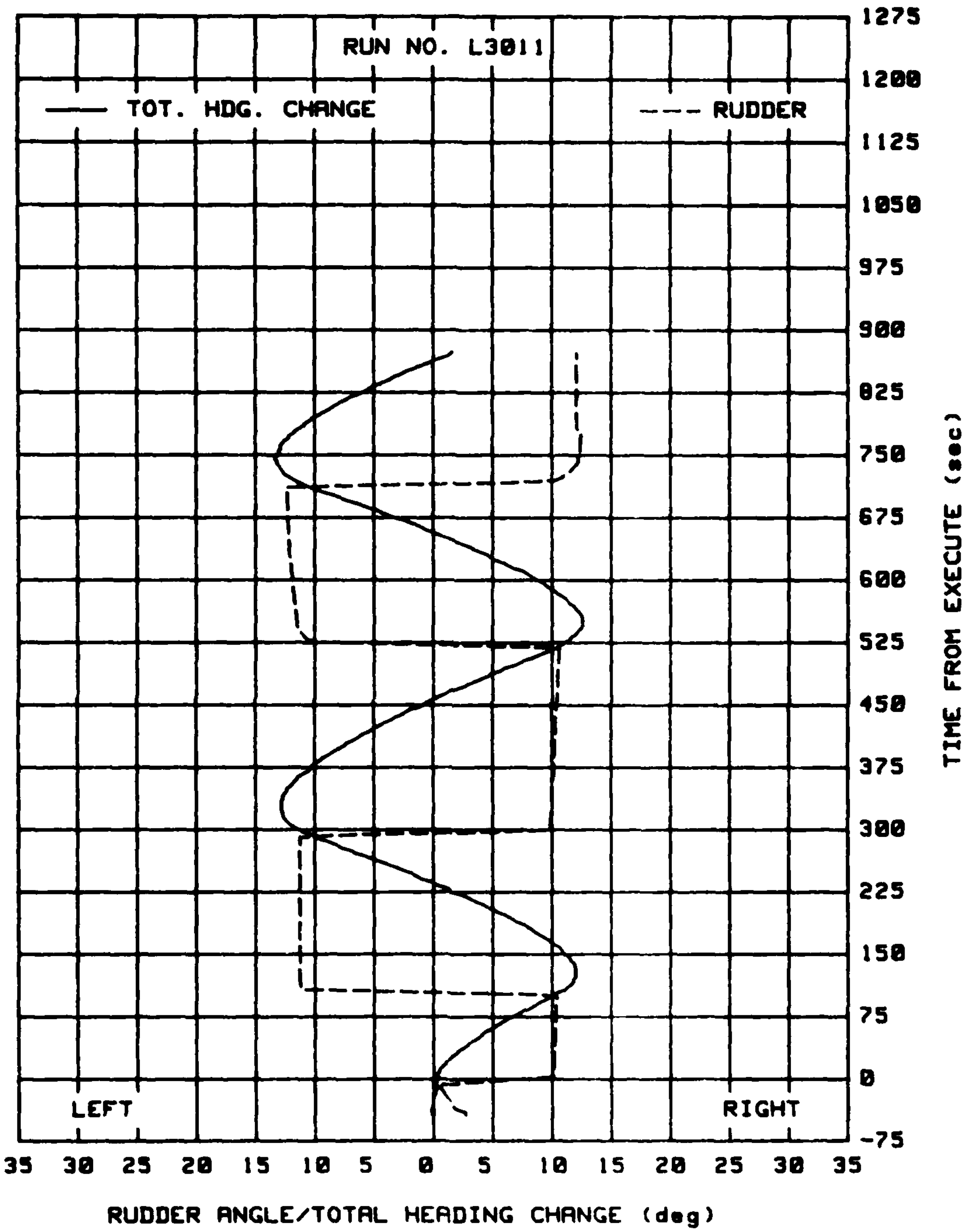


Figure 98 - Rudder and Heading Changes during Full Ahead, 10/10 Degrees Overshoot Maneuver (Run L3011)

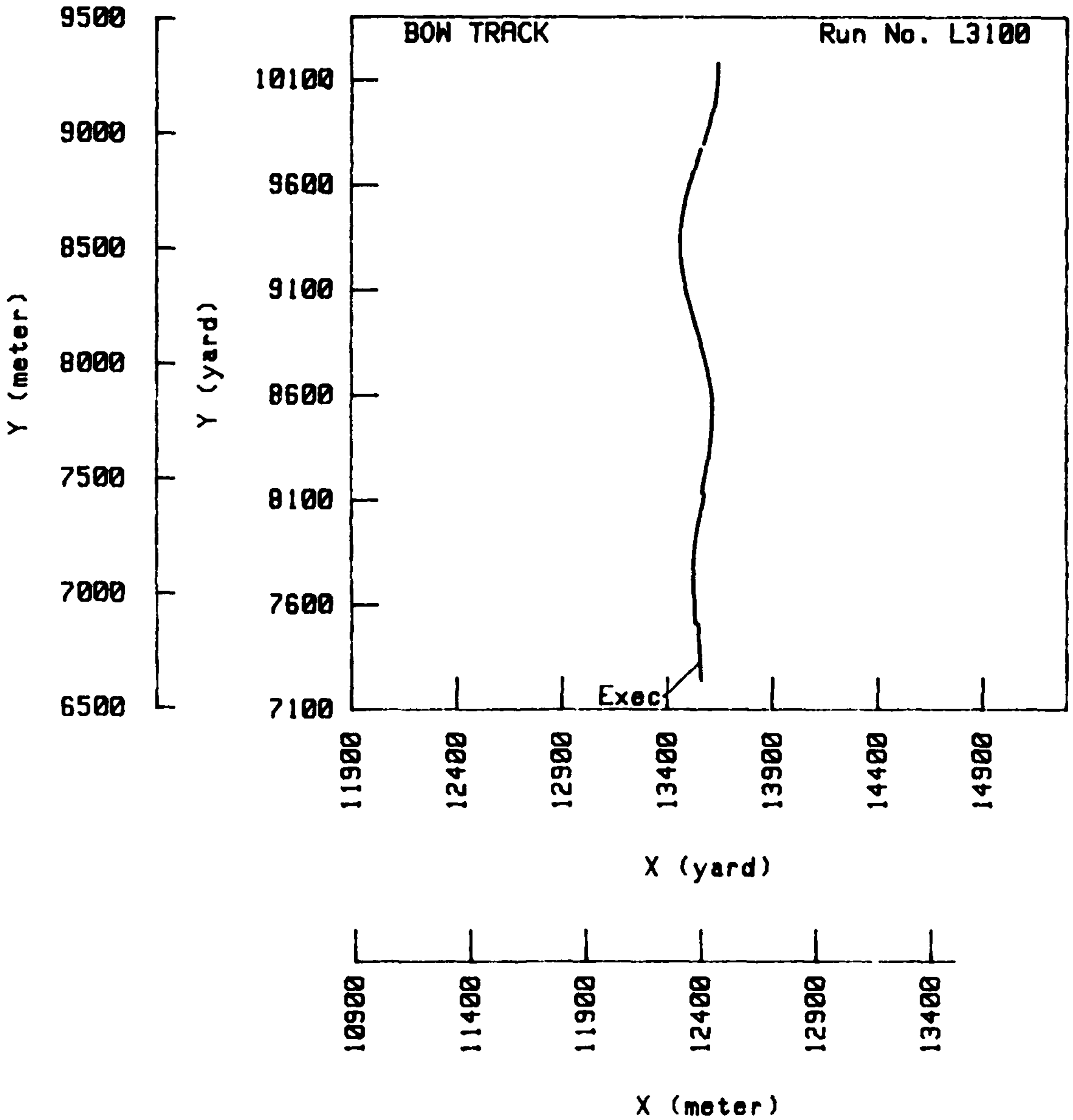


Figure 99 - Position Plot for Full Astern, 10/10 Degrees Overshoot Maneuver (Run L3100)

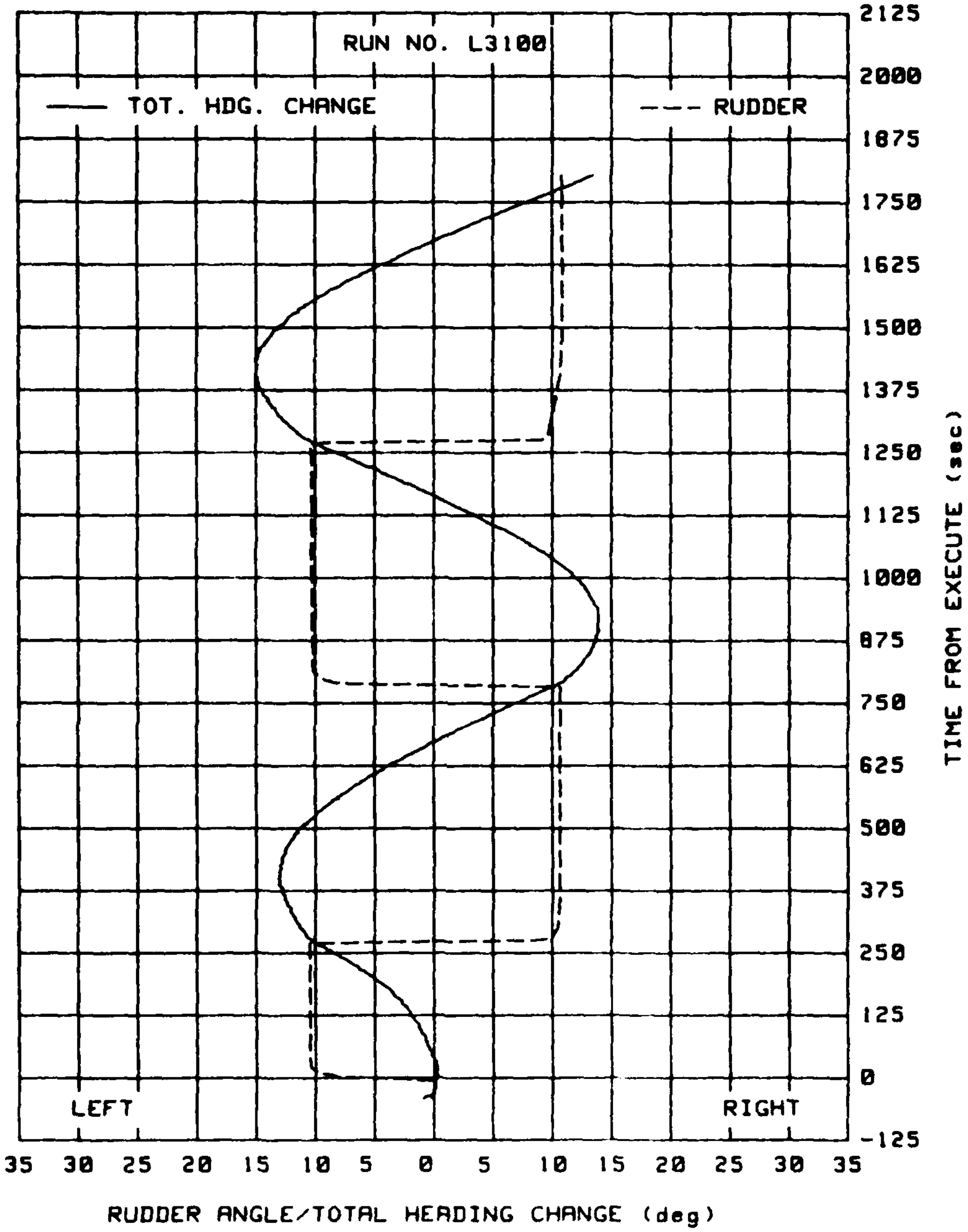


Figure 100 - Rudder and Heading Changes during Full Astern, 10/10 Degrees Overshoot Maneuver (Run L3100)

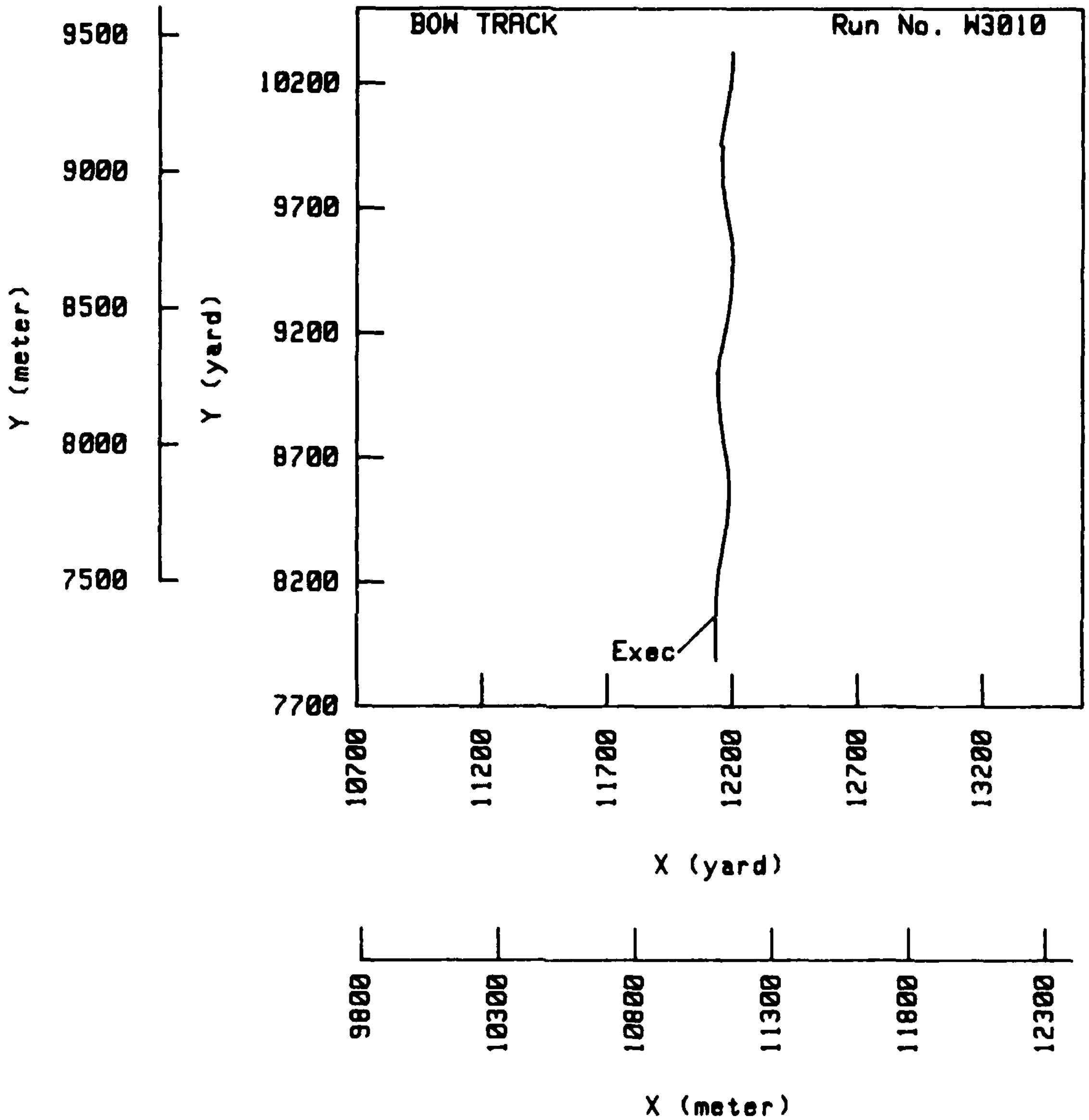


Figure 101 - Position Plot for Full Ahead, 10/10 Degrees Overshoot Maneuver (Run W3010)

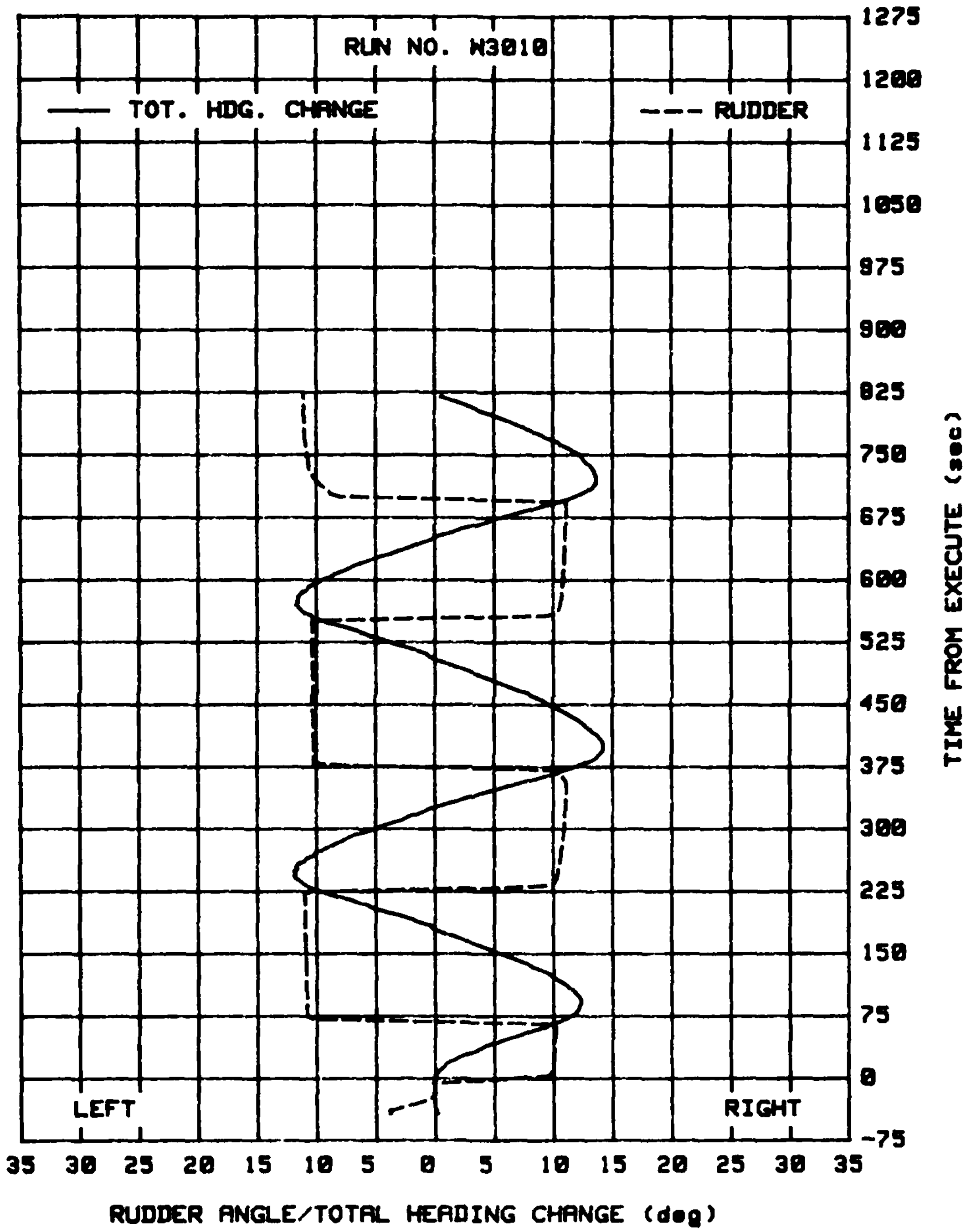


Figure 102 - Rudder and Heading Changes during Full Ahead, 10/10 Degrees Overshoot Maneuver (Run W3010)

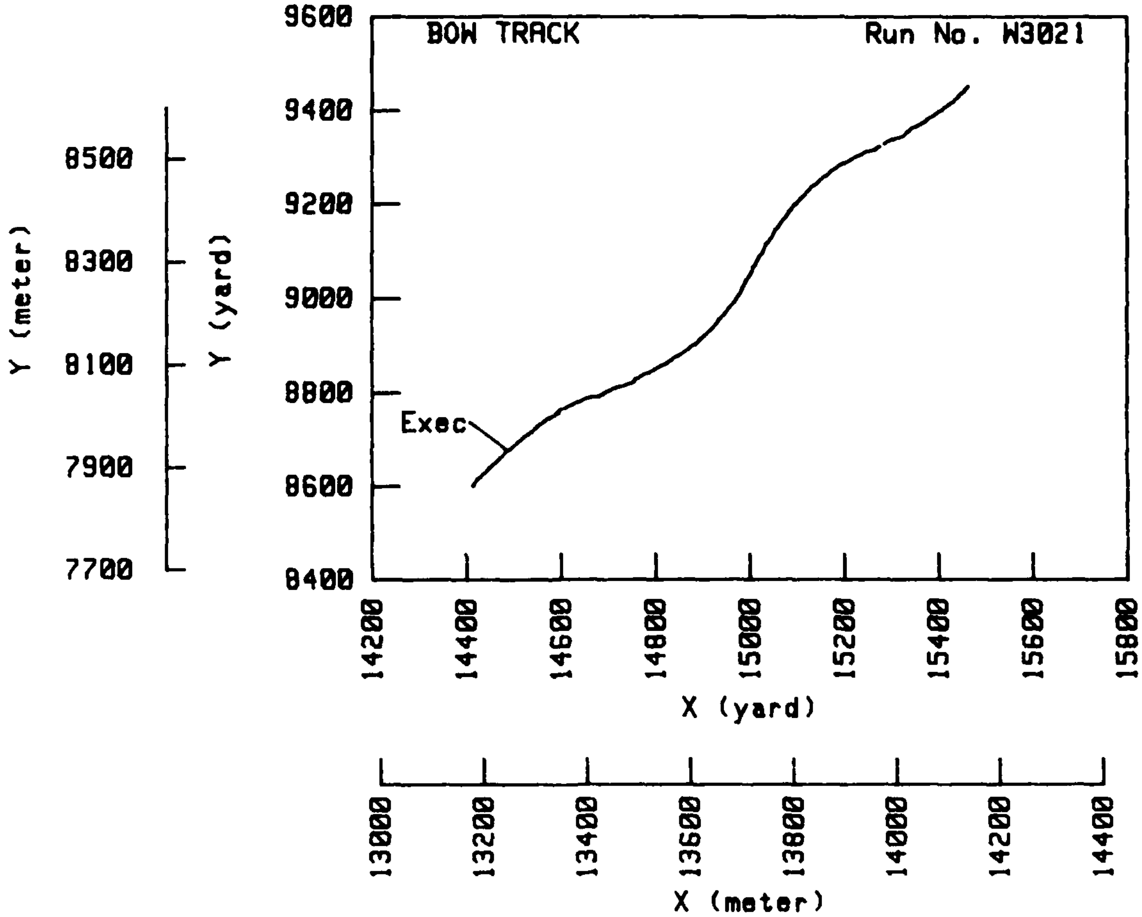


Figure 103 - Position Plot for Full Ahead, 10/10 Degrees Overshoot Maneuver (Run W3021)

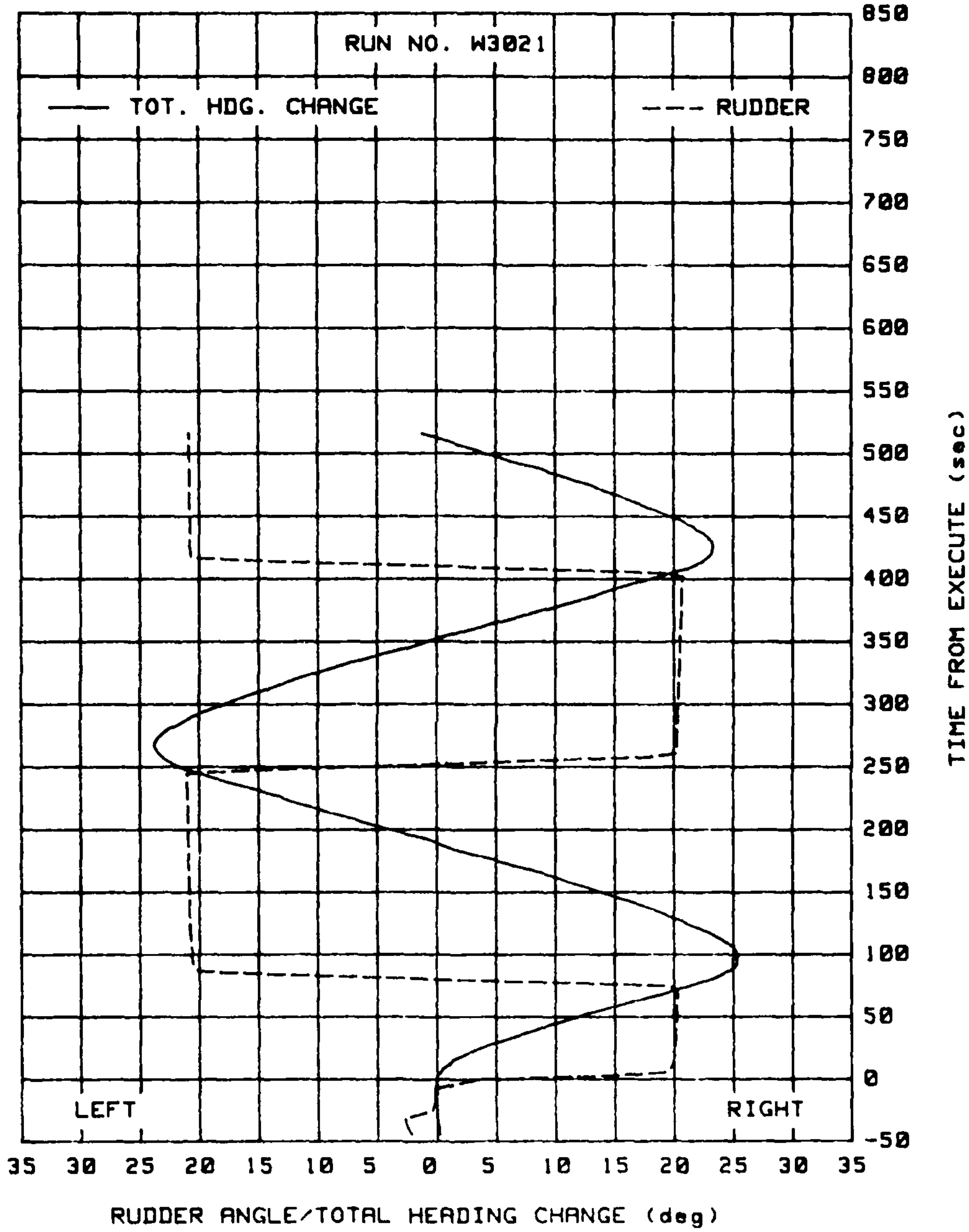


Figure 104 - Rudder and Heading Changes During Full Ahead, 20/20 Degrees Overshoot Maneuver (Run W3021)

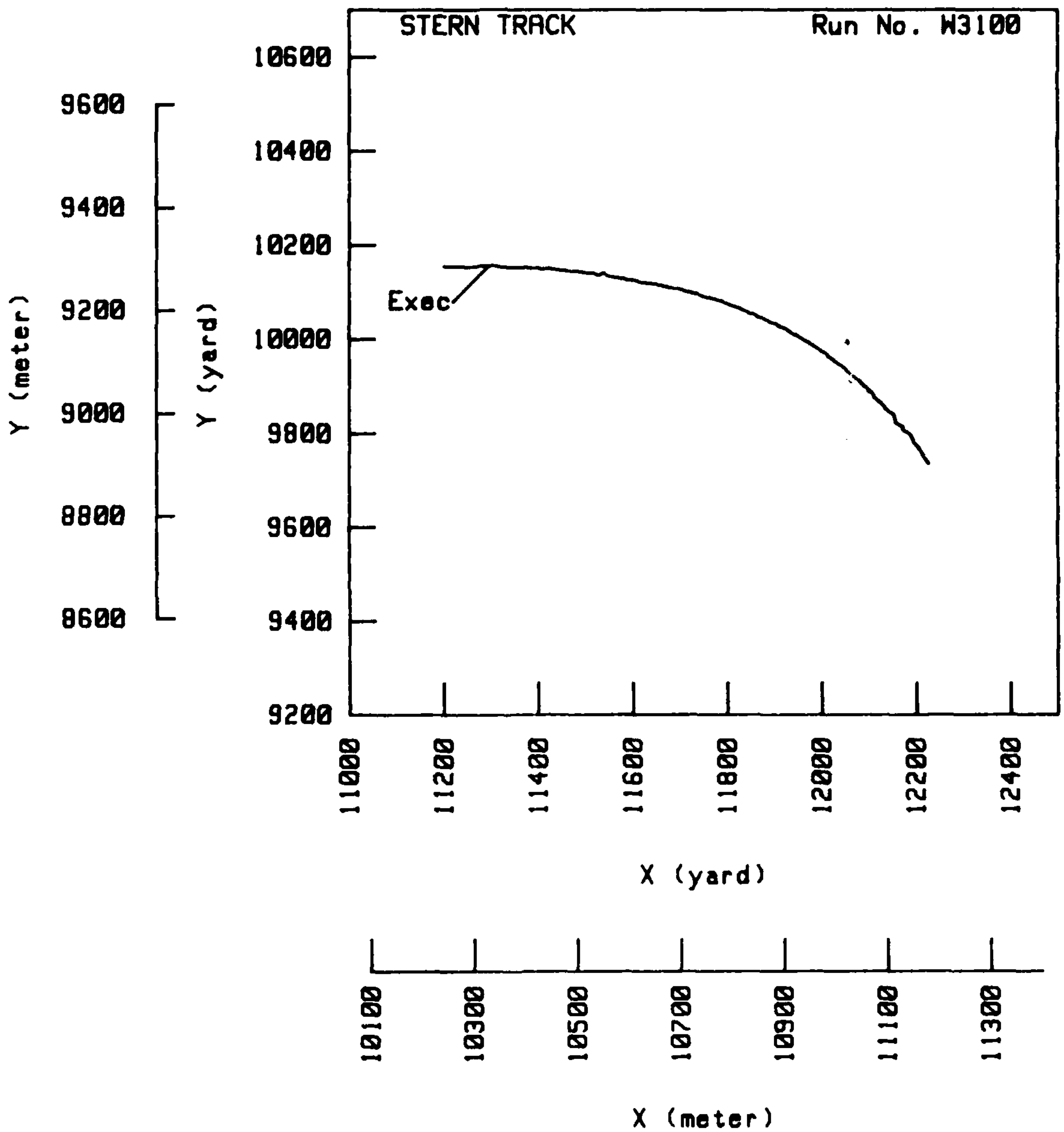


Figure 105 - Position Plot for Full Astern, 10/10 Degrees Overshoot Maneuver (Run W3100)

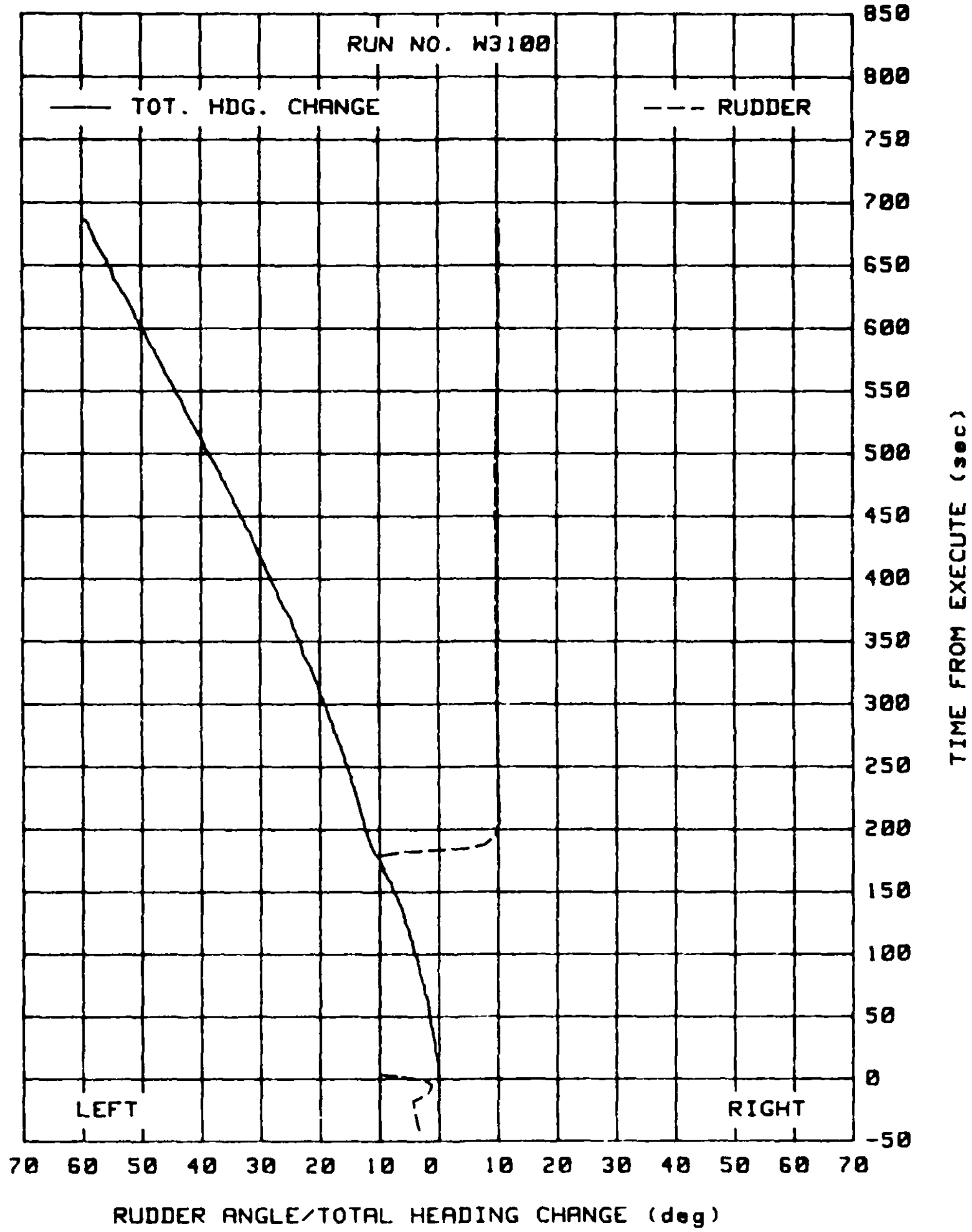


Figure 106 - Rudder and Heading Changes during Full Astern, 10/10 Degrees Overshoot Maneuver (Run W3100)

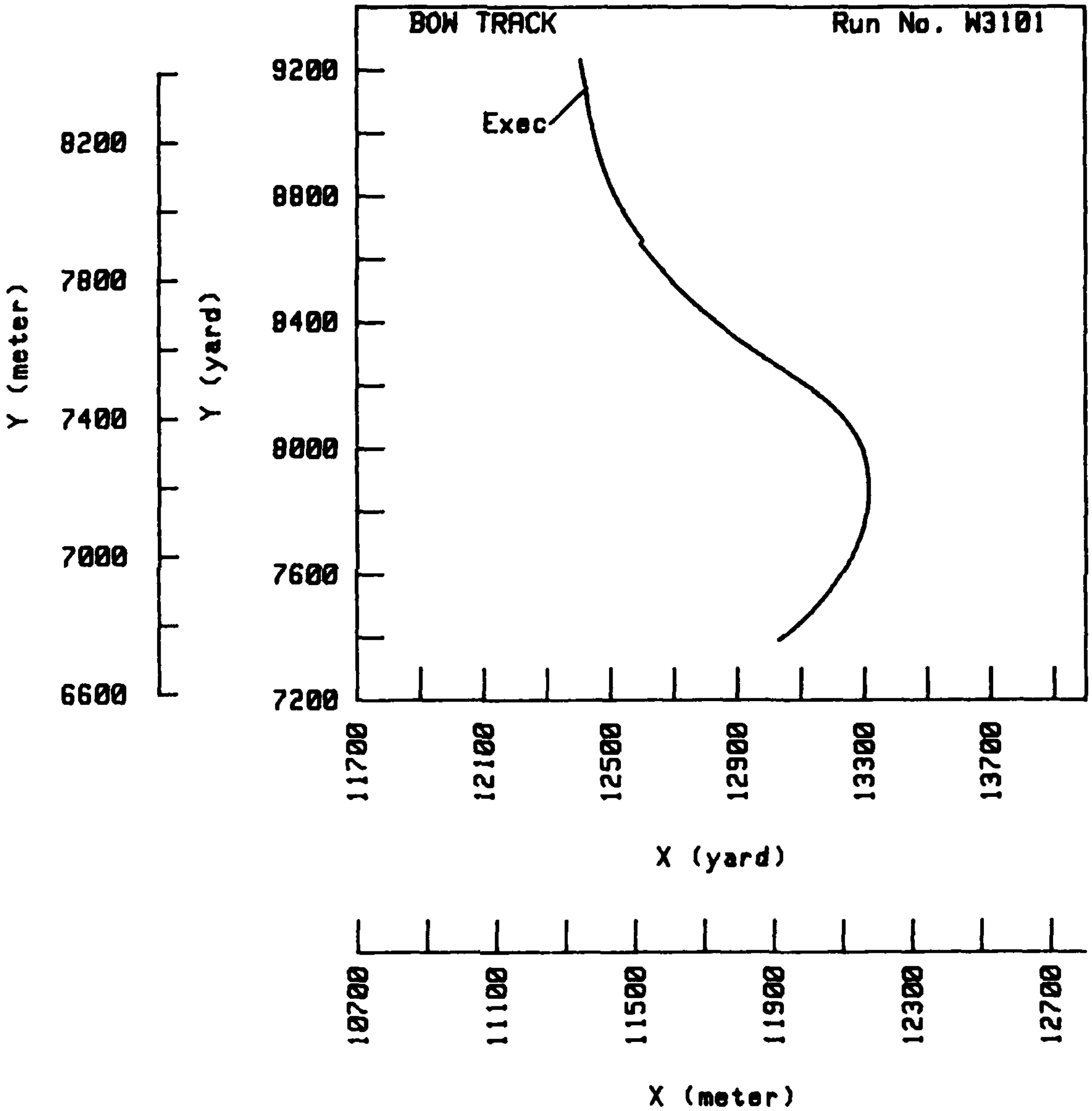


Figure 107 - Position Plot for Full Astern, 10/10 Degrees Overshoot Maneuver (Run W3101)

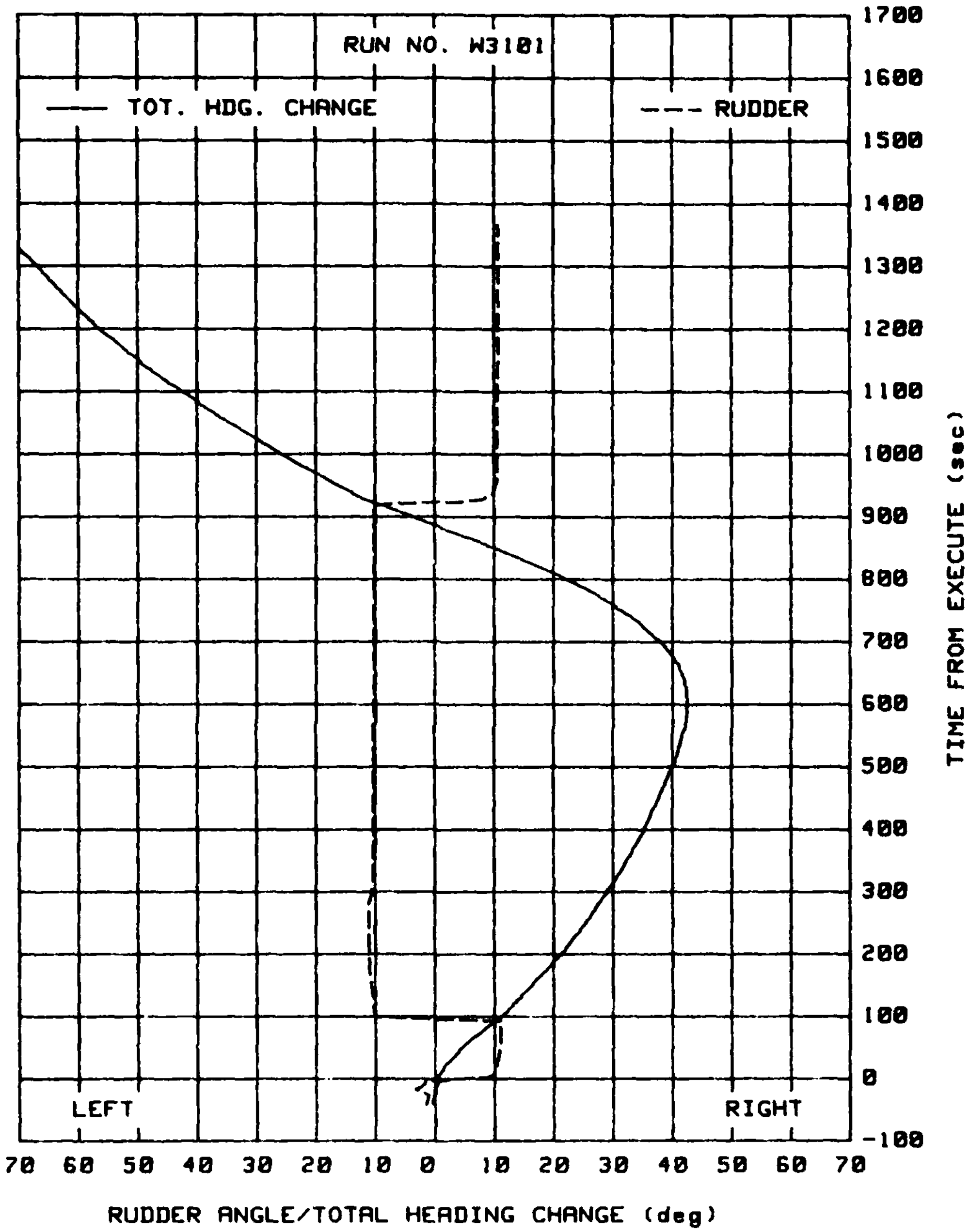


Figure 108 - Rudder and Heading Changes during Full Astern, 10/10 Degrees Overshoot Maneuver (Run W3101)

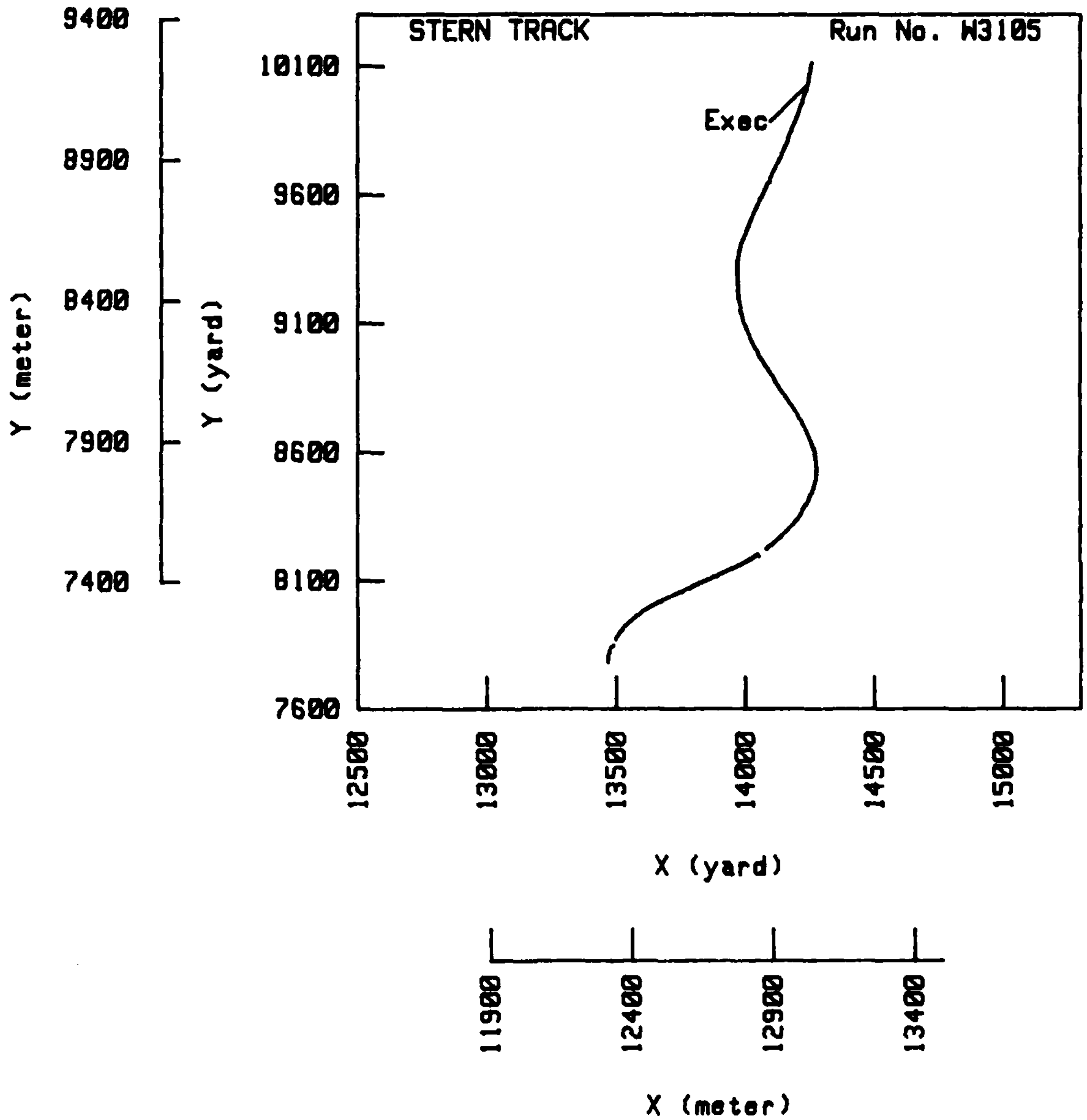


Figure 109 - Position Plot for Full Astern, 10/20 Degrees Overshoot Maneuver (Run W3105)

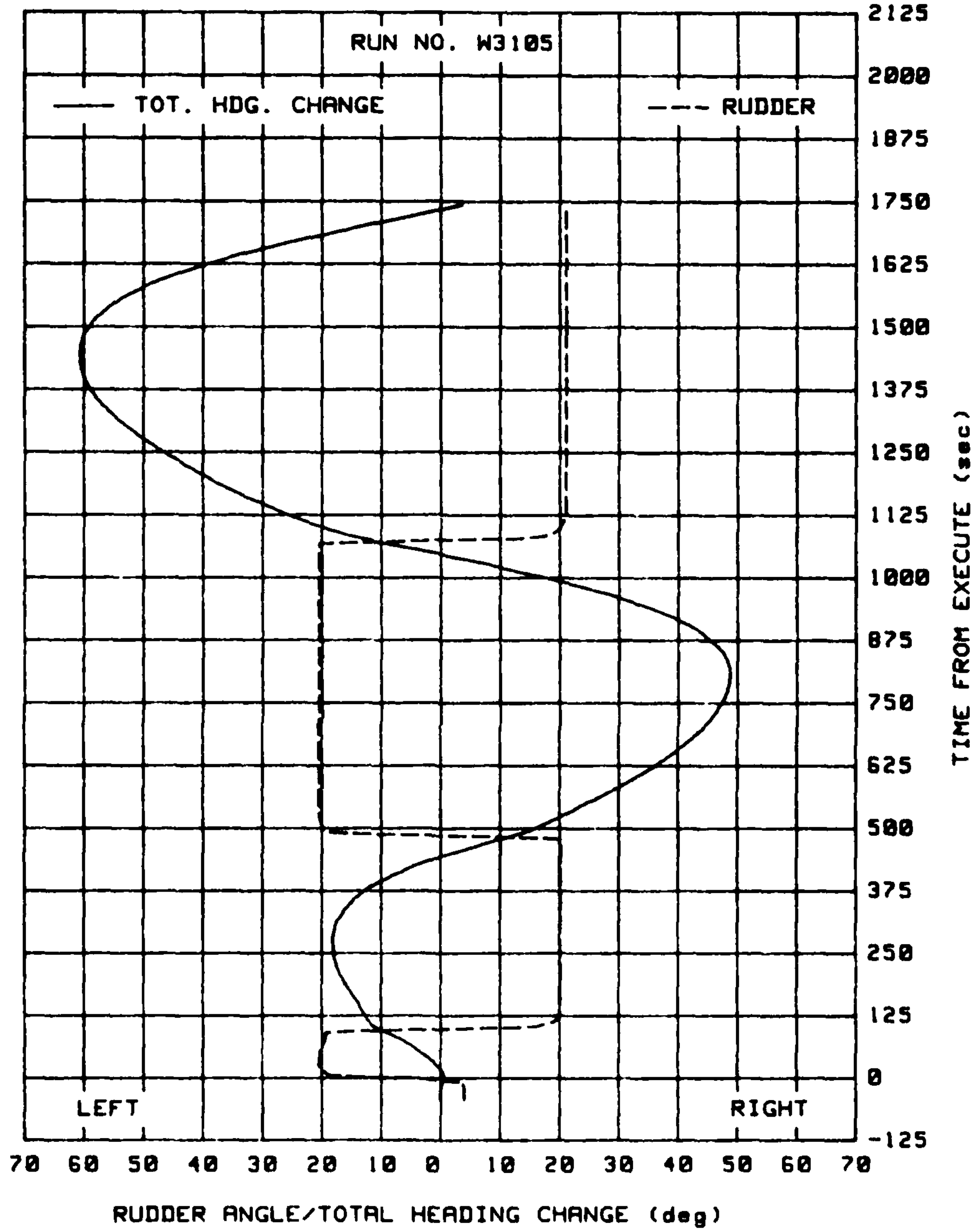


Figure 110 - Rudder and Heading Changes during Full Astern, 10/20 Degrees Overshoot Maneuver (Run W3105)

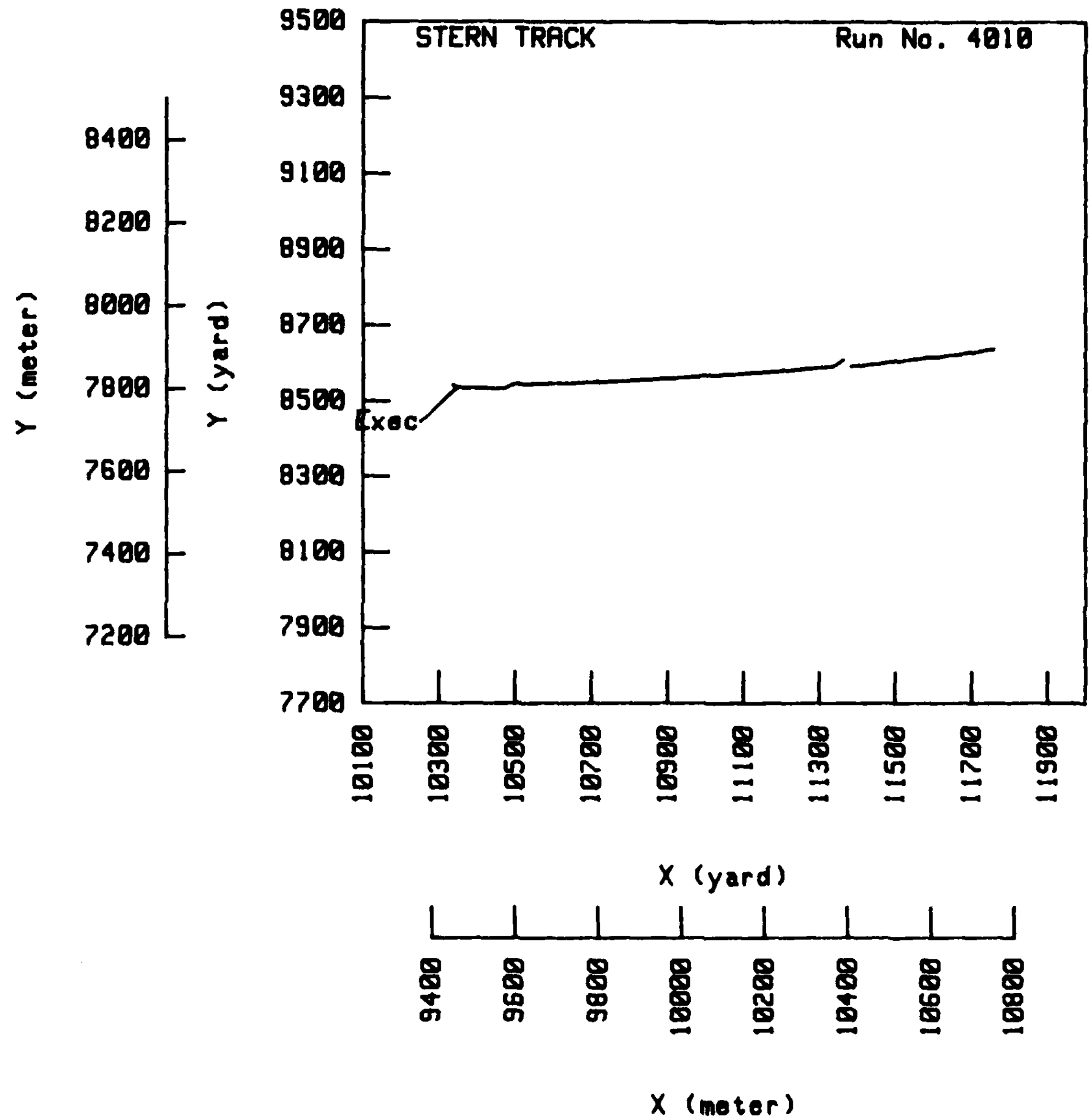


Figure 111 - Position Plot for All Stop to Full Ahead Acceleration Maneuver (Run 4010)

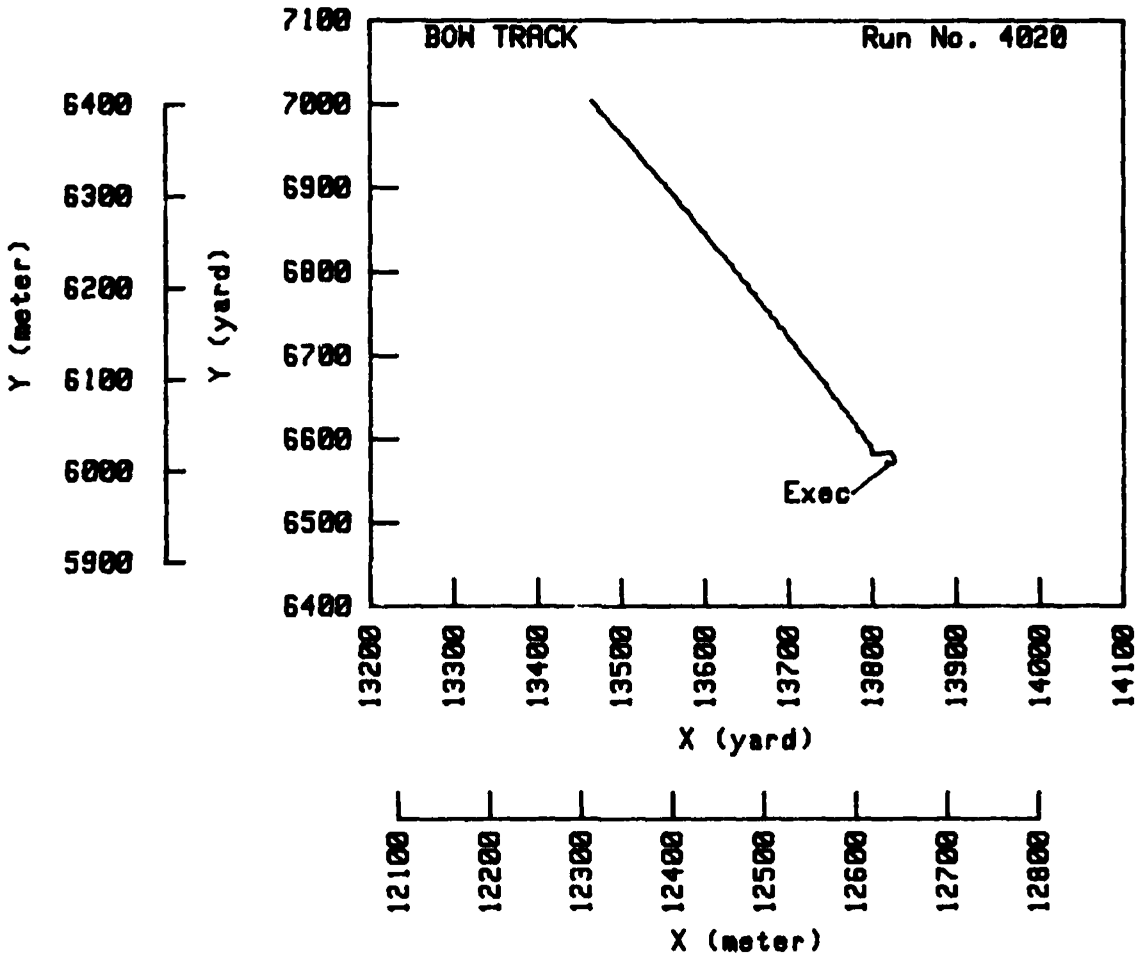


Figure 112 - Position Plot for All Stop to Half Ahead Acceleration Maneuver (Run 4020)

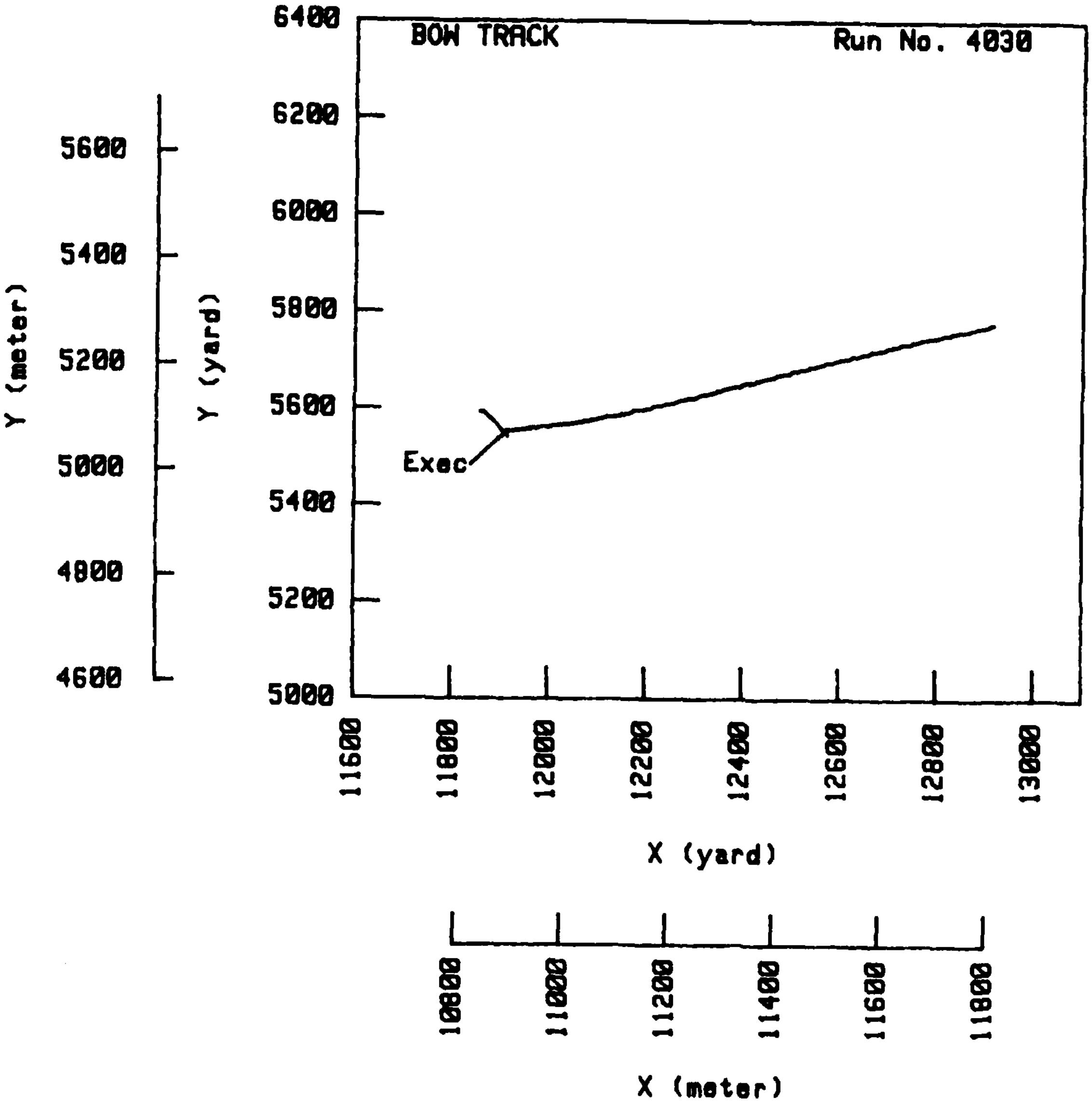


Figure 113 - Position Plot for All Stop to Full Astern Acceleration Maneuver (Run 4030)

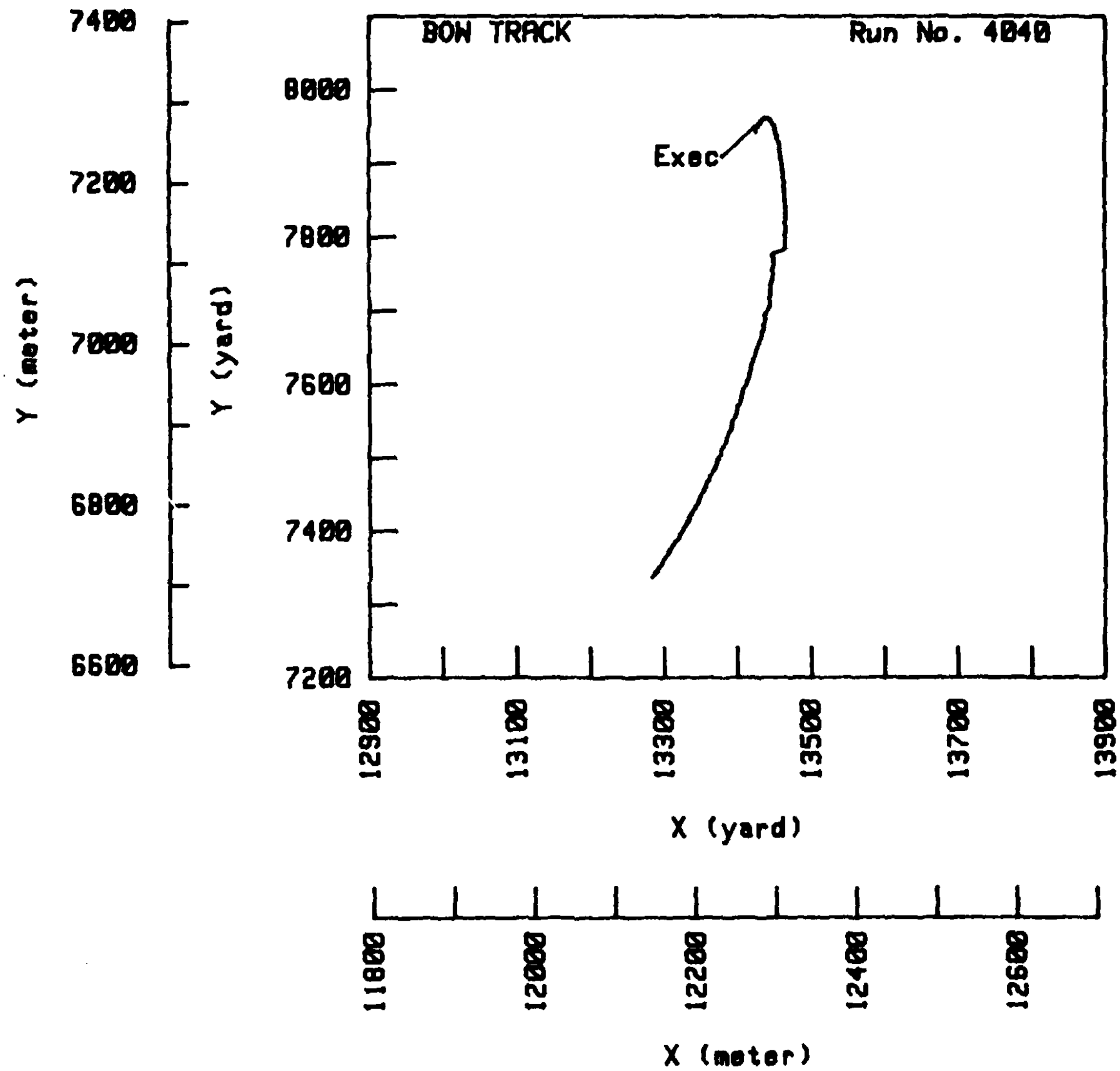


Figure 114 - Position Plot for All Stop to Half Astern Acceleration Maneuver (Run 4040)

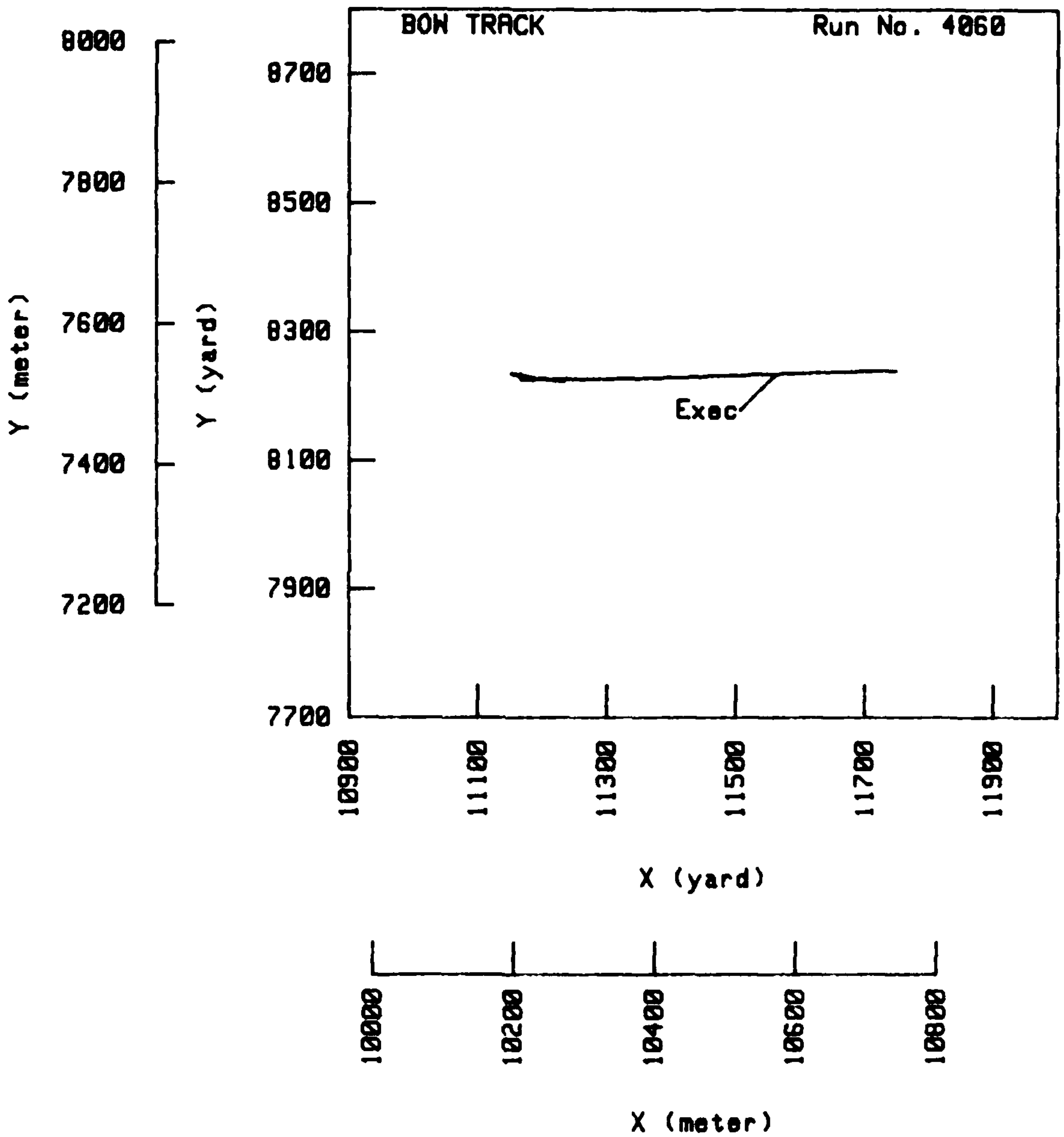


Figure 115 - Position Plot for Full Ahead to Full Astern Deceleration Maneuver (Run 4060)

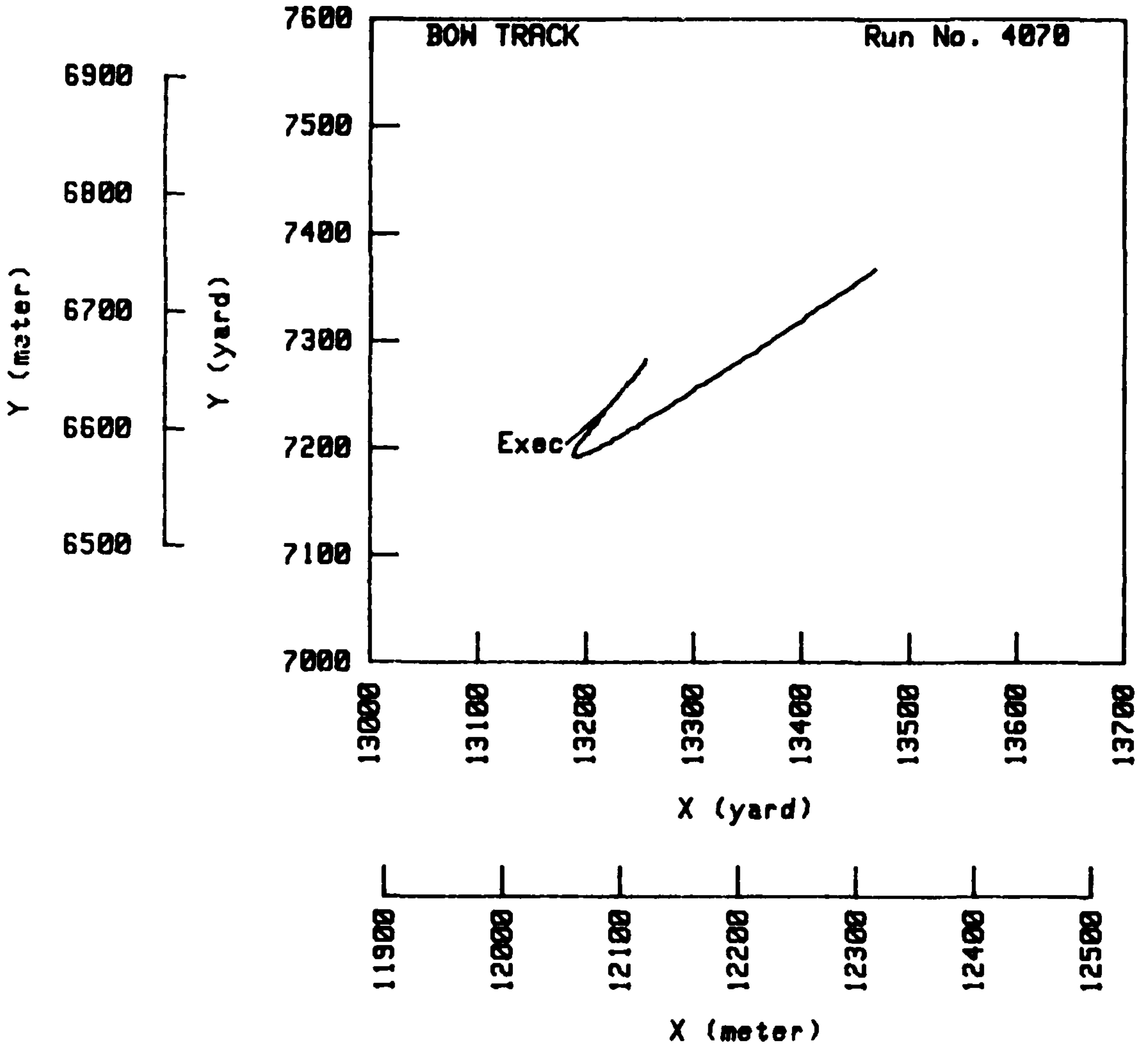


Figure 116 - Position Plot for Half Astern to Full Ahead Acceleration Maneuver (Run 4070)

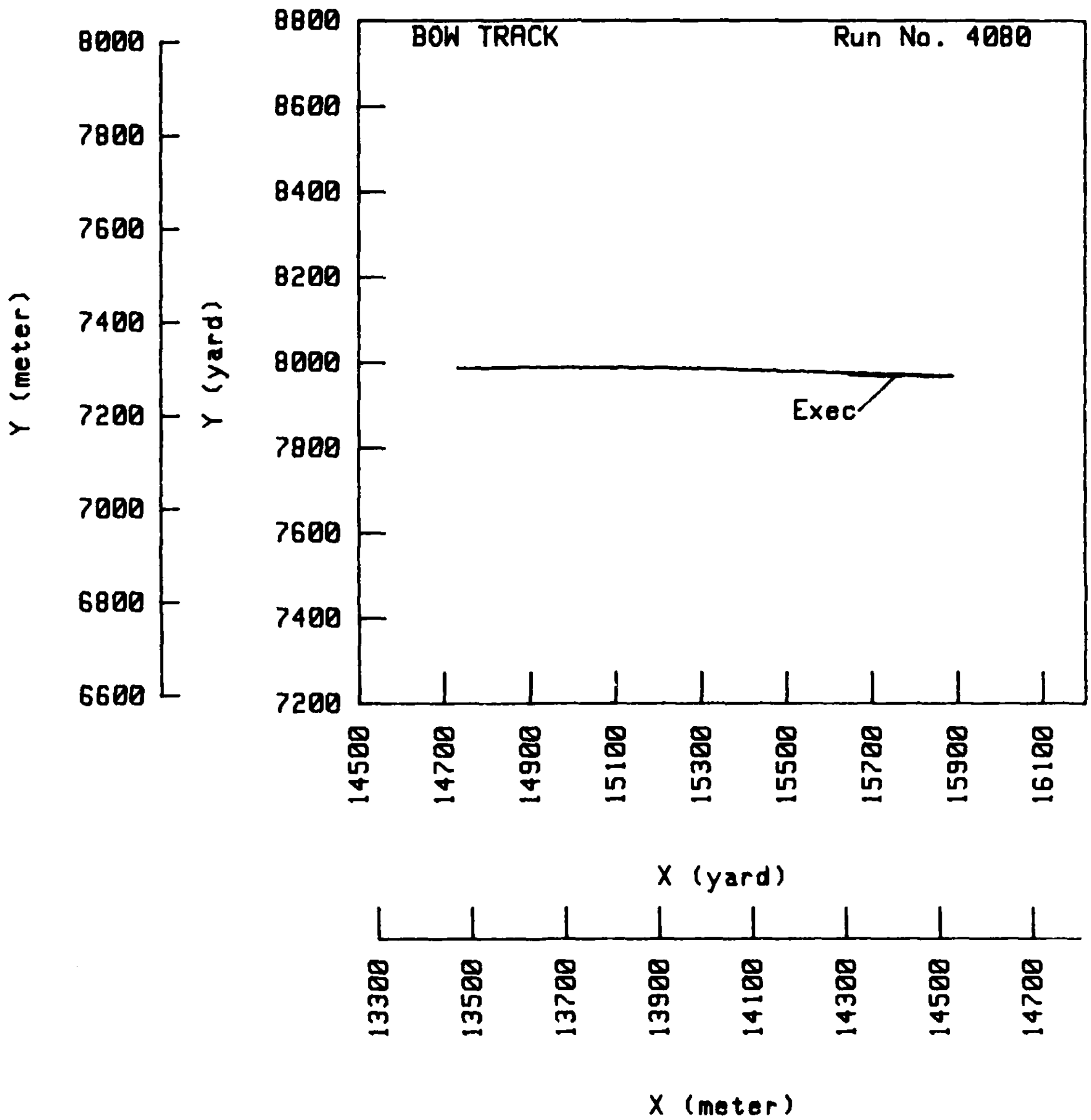


Figure 117 - Position Plot for Full Astern to Full Ahead Acceleration Maneuver (Run 4080)

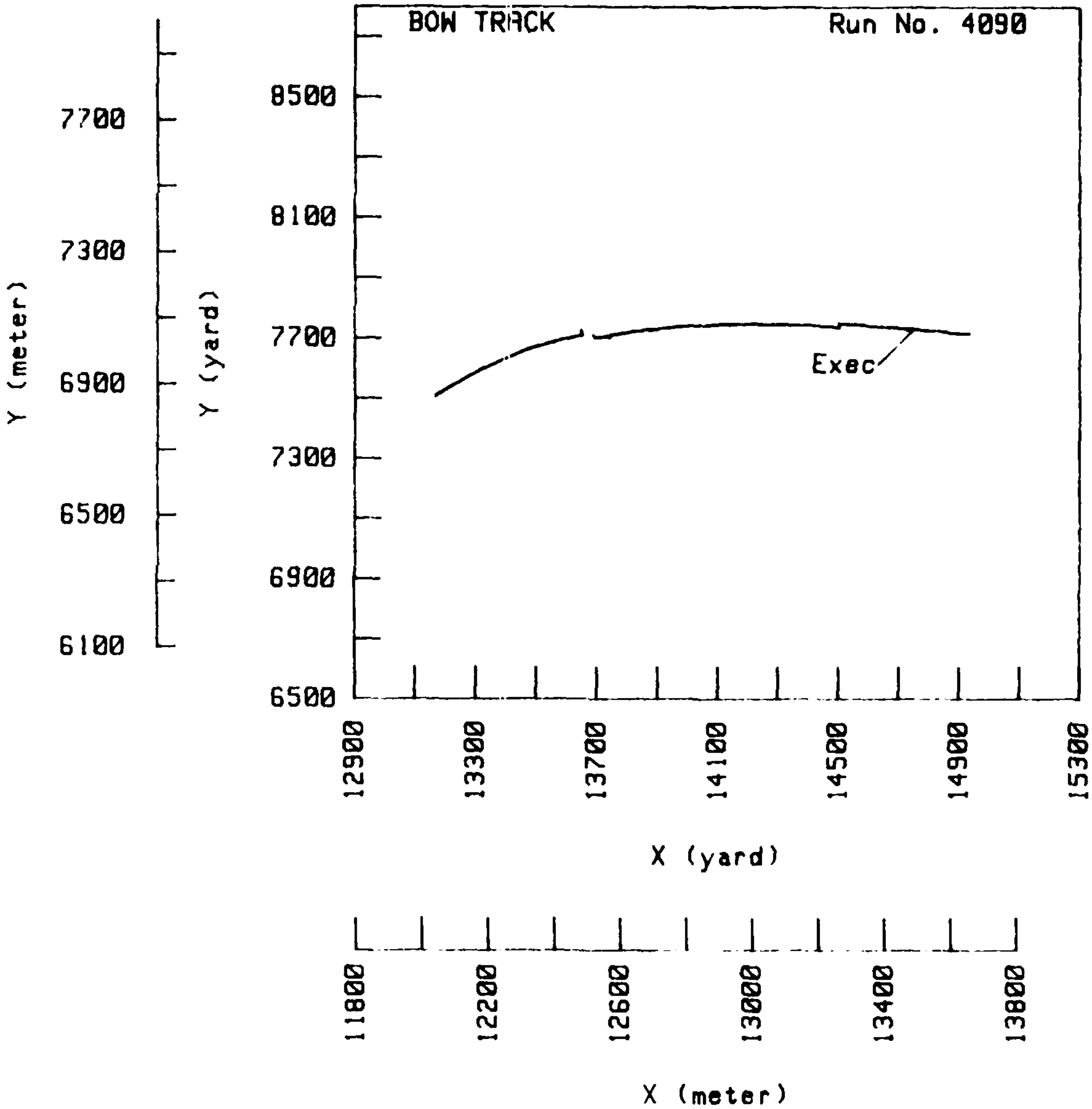


Figure 118 - Position Plot for Full Ahead to All Stop Deceleration Maneuver (Run 4090)

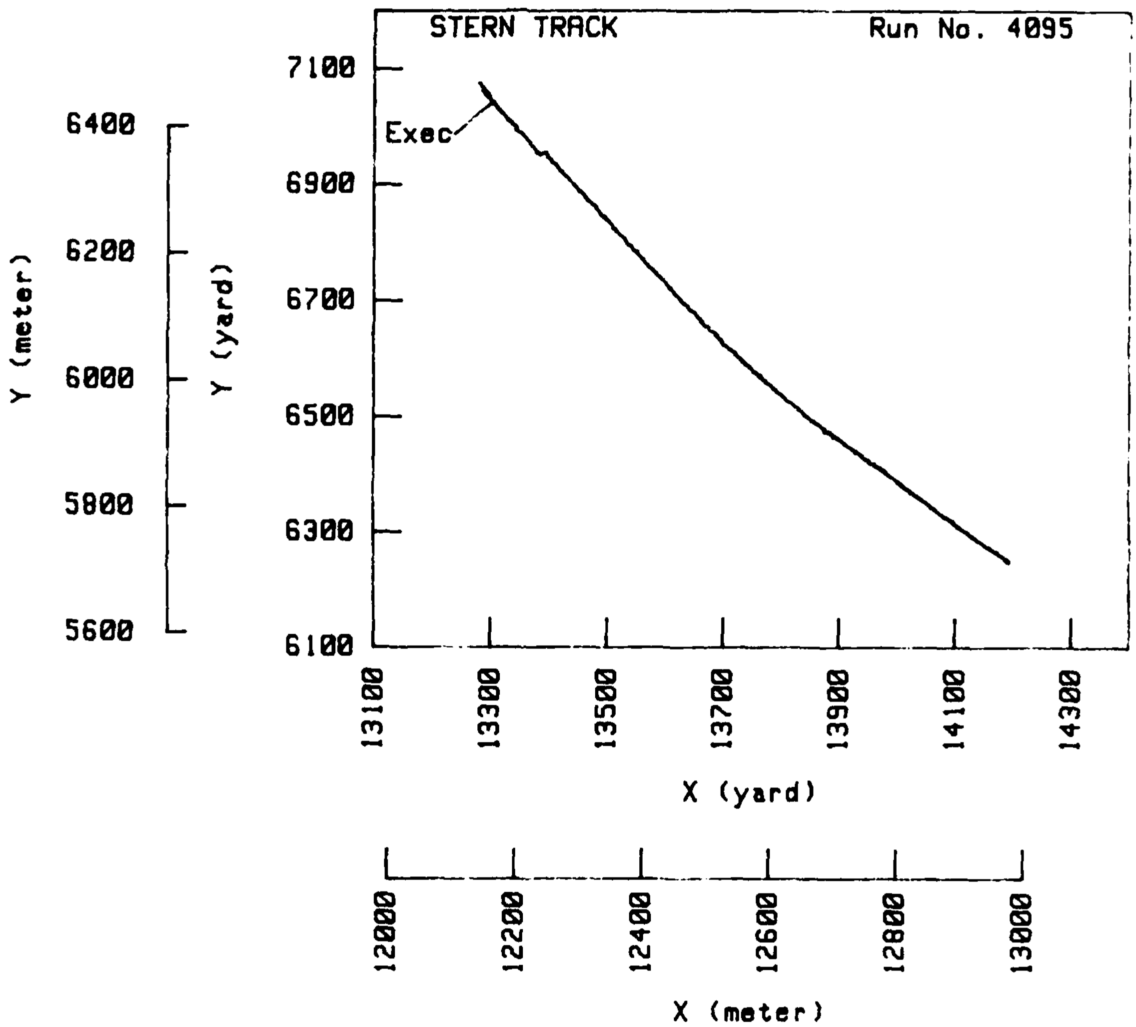


Figure 119 - Position Plot for Full Astern to All Stop Deceleration Maneuver (Run 4095)

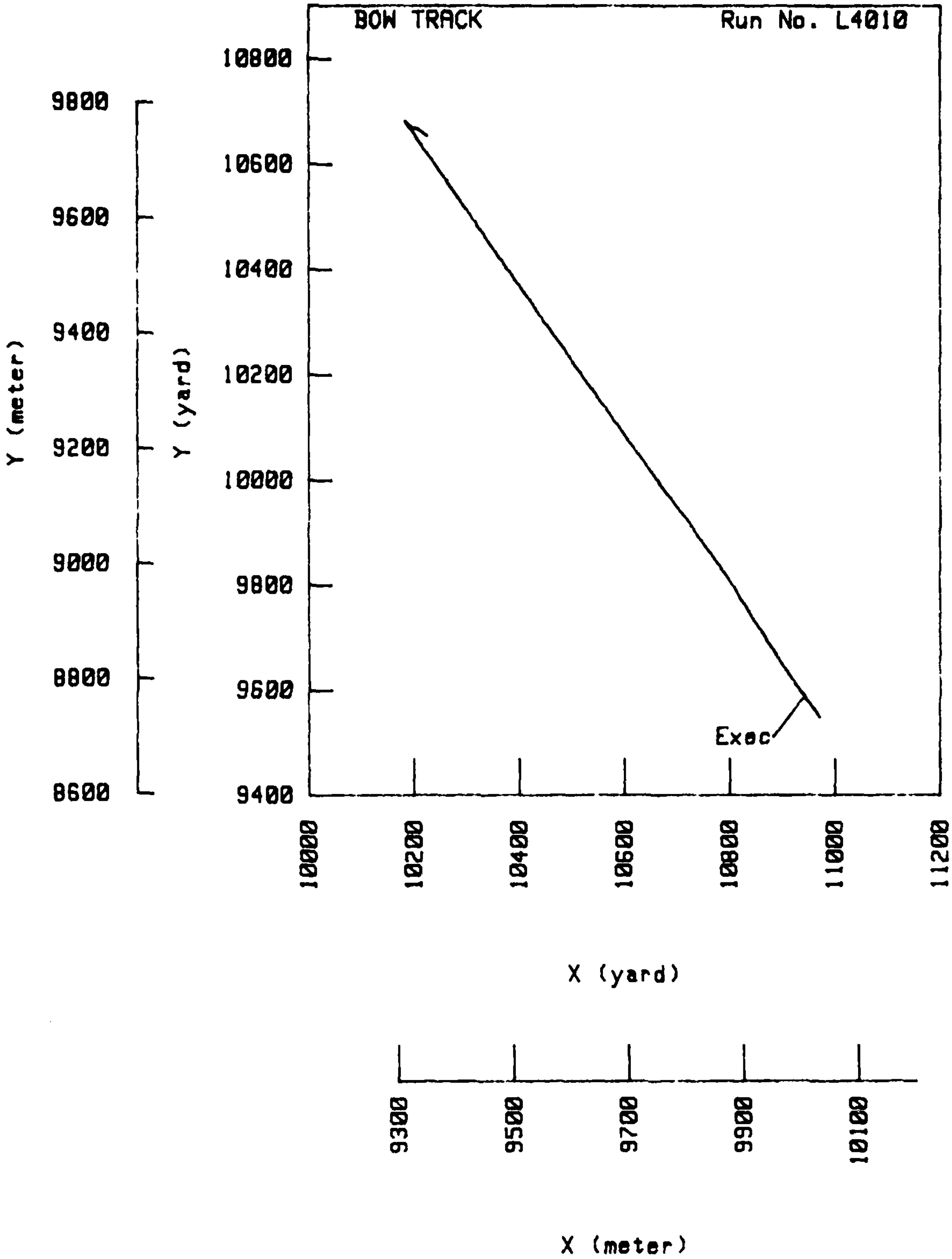


Figure 120 - Position Plot for All Stop to Full Ahead Acceleration Maneuver (Run L4010)

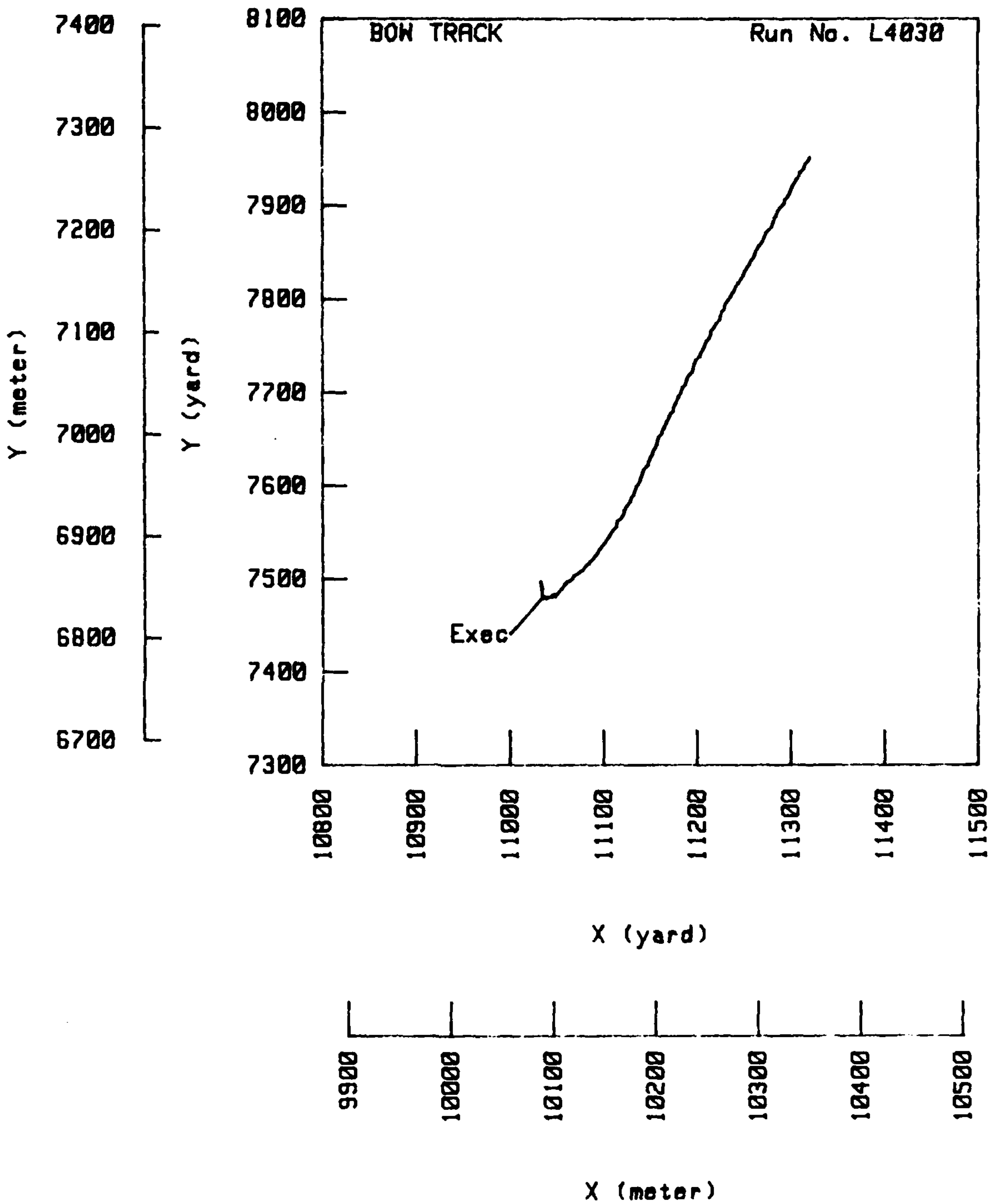


Figure 121 - Position Plot for All Stop to Full Astern Acceleration Maneuver (Run L4030)

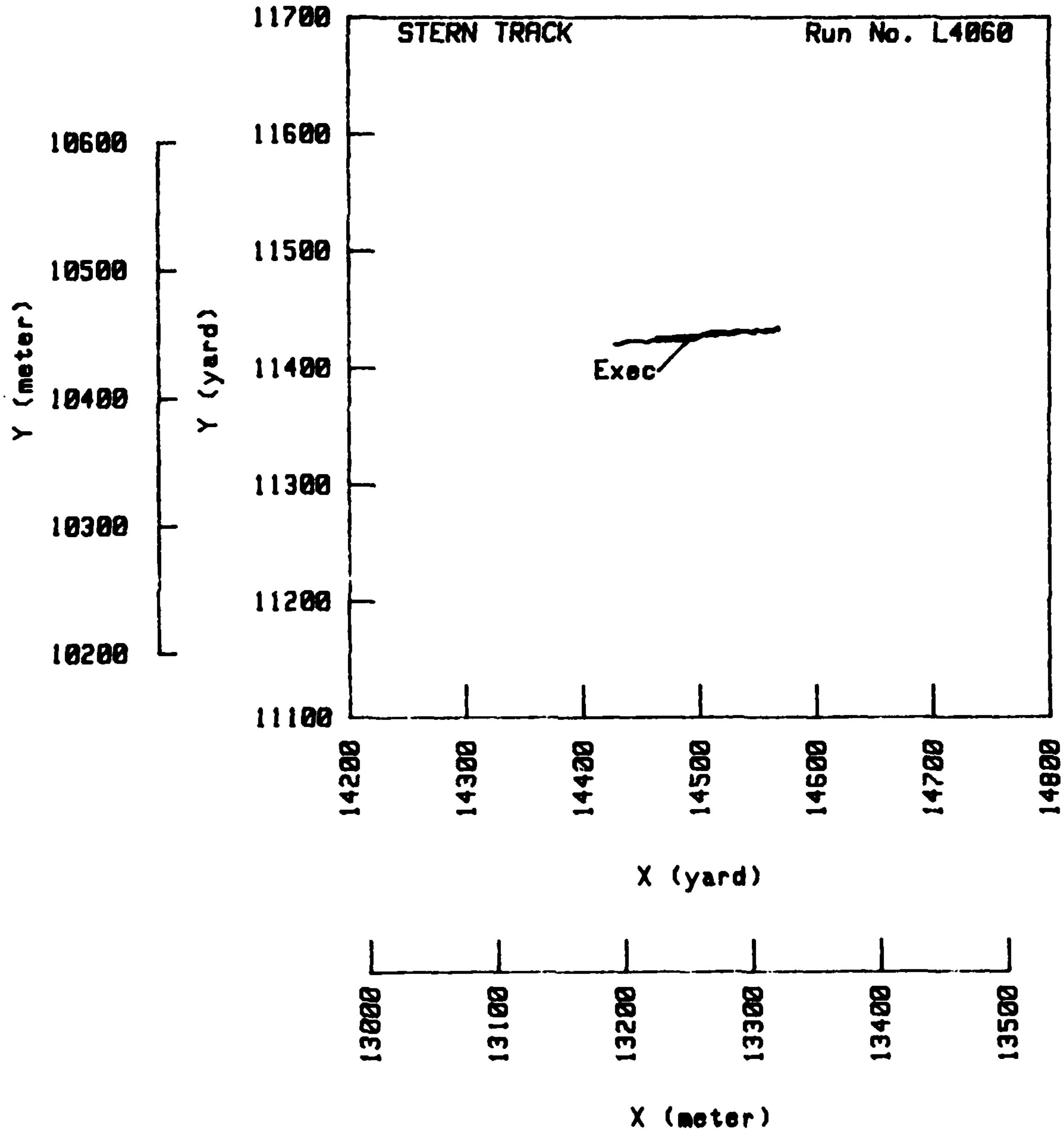


Figure 122 - Position Plot for Full Astern to Full Ahead Acceleration Maneuver (Run L4060)

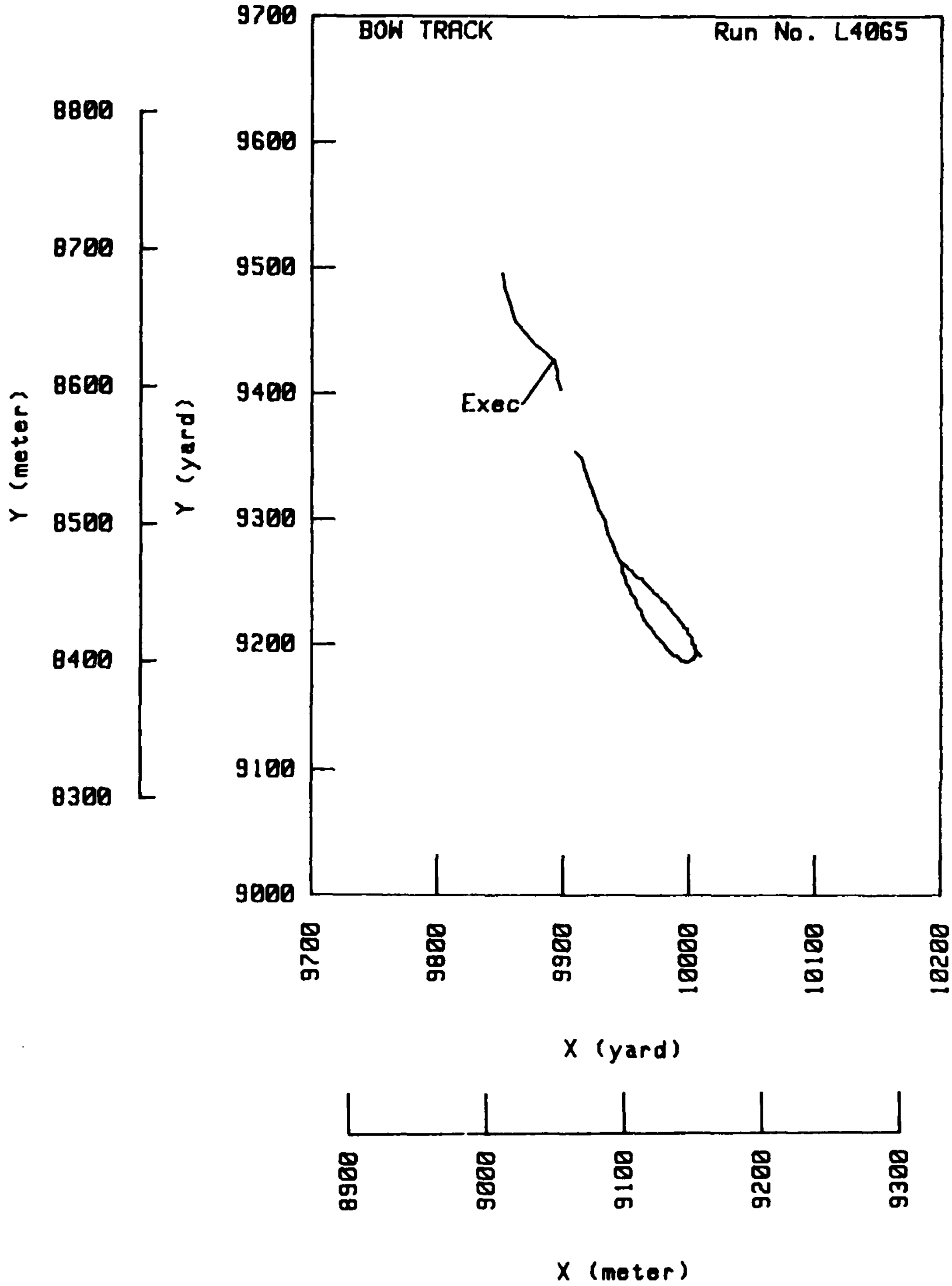


Figure 123 - Position Plot for Full Ahead to Full Astern Deceleration Maneuver (Run L4065)

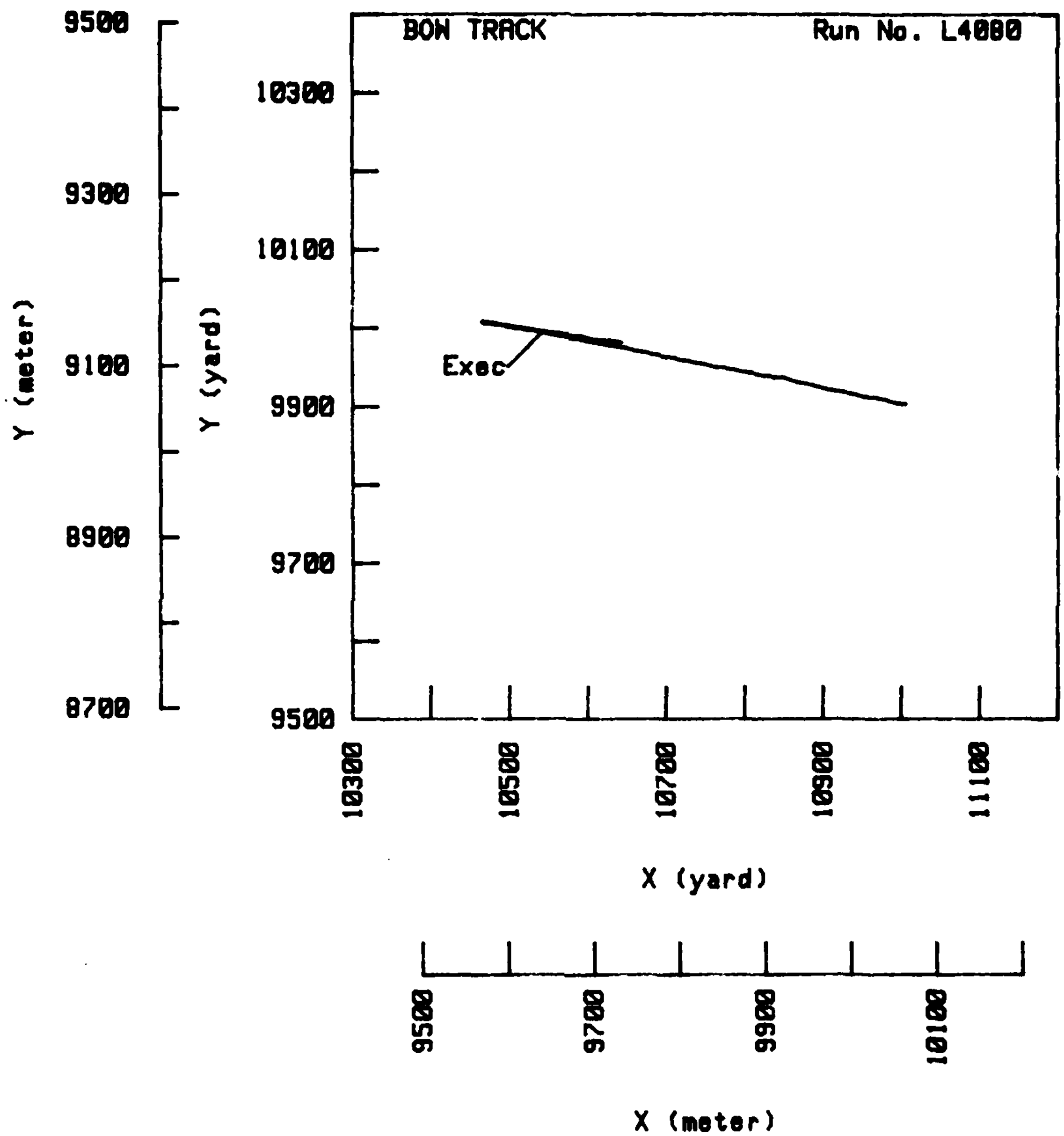


Figure 124 - Position Plot for Full Astern to Full Ahead Acceleration Maneuver (Run L4080)

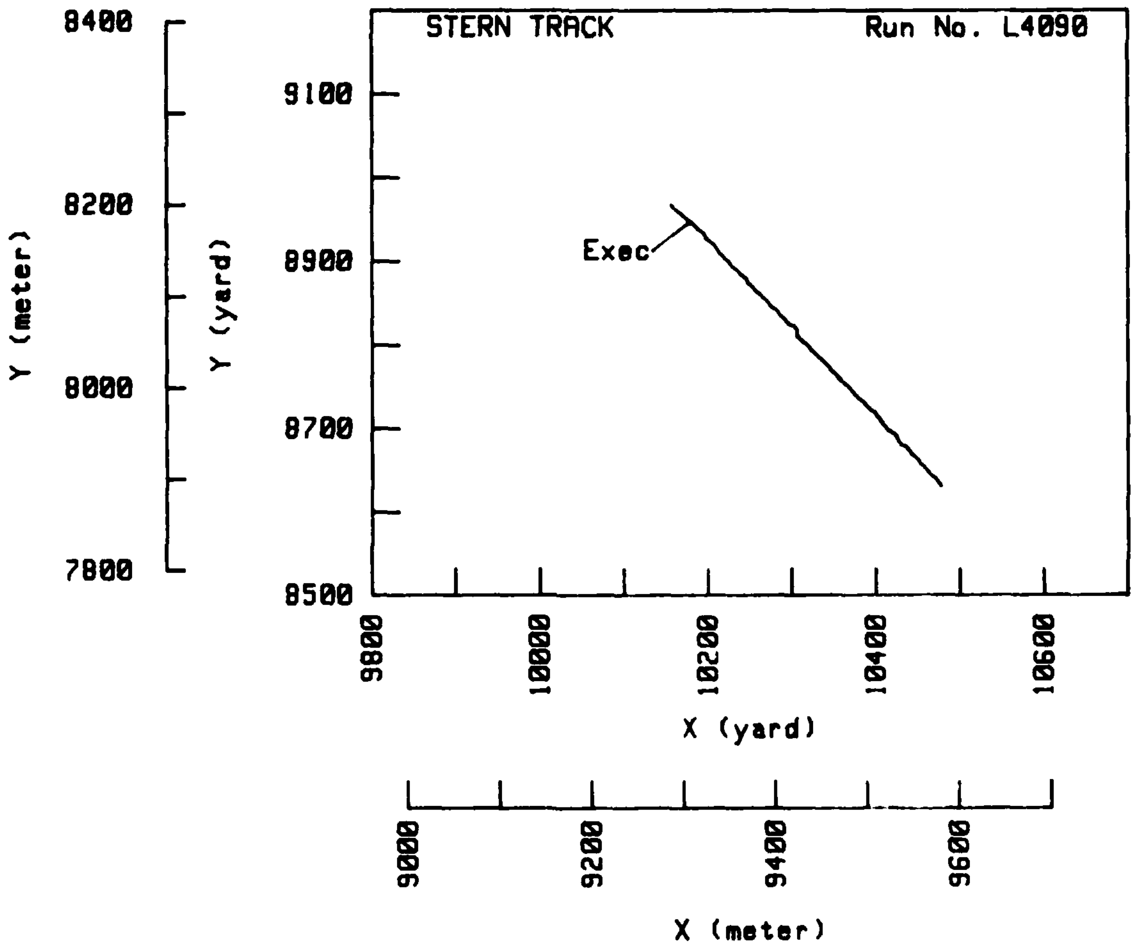


Figure 125 - Position Plot for Full Ahead to All Stop Deceleration Maneuver (Run L4090)

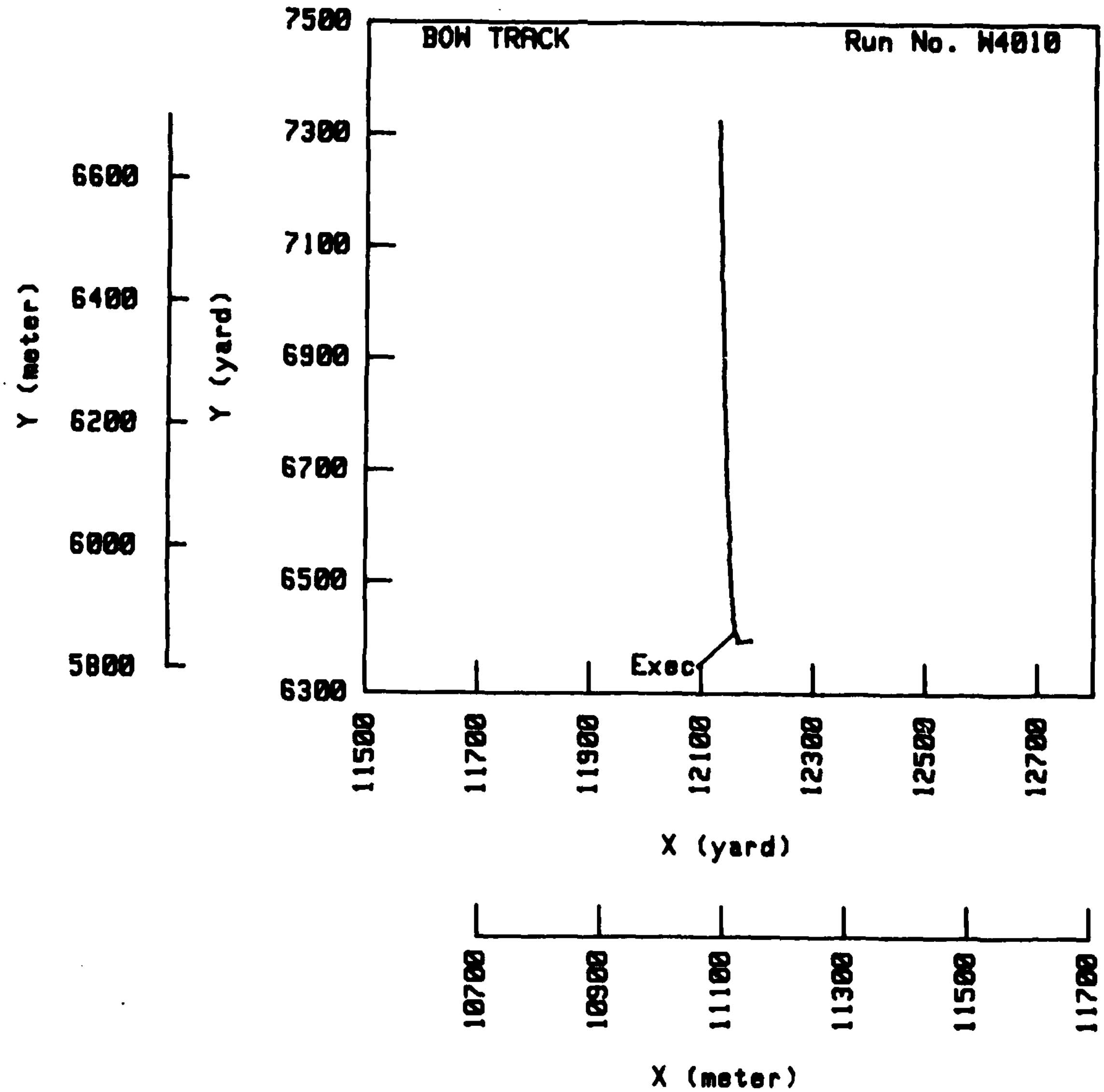


Figure 126 - Position Plot for All Stop to Full Ahead Acceleration Maneuver (Run W4010)

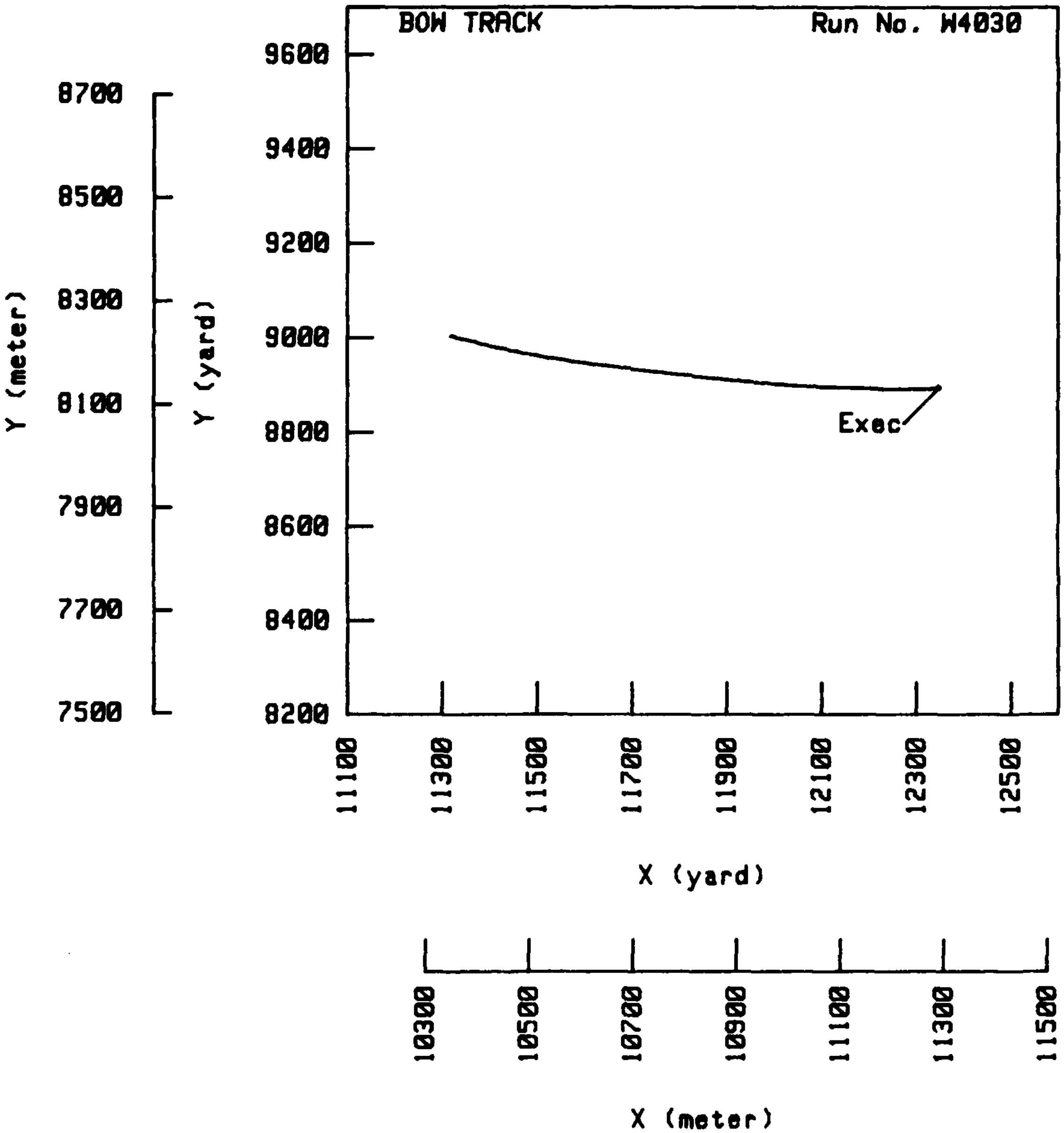


Figure 127 - Position Plot for All Stop to Full Astern Acceleration Maneuver (Run W4030)

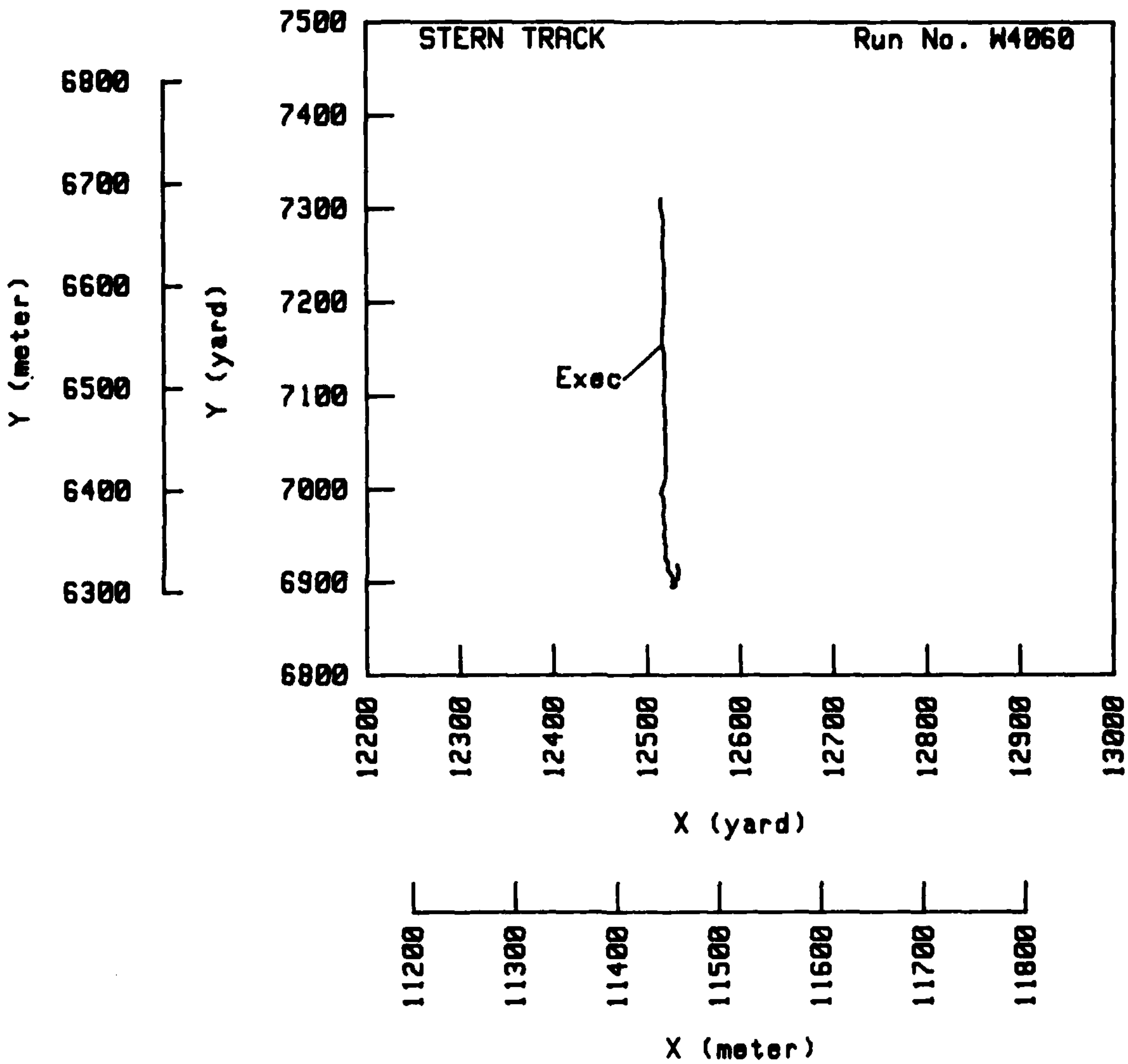


Figure 128 - Position Plot for Full Ahead to Full Astern Deceleration Maneuver (Run W4060)

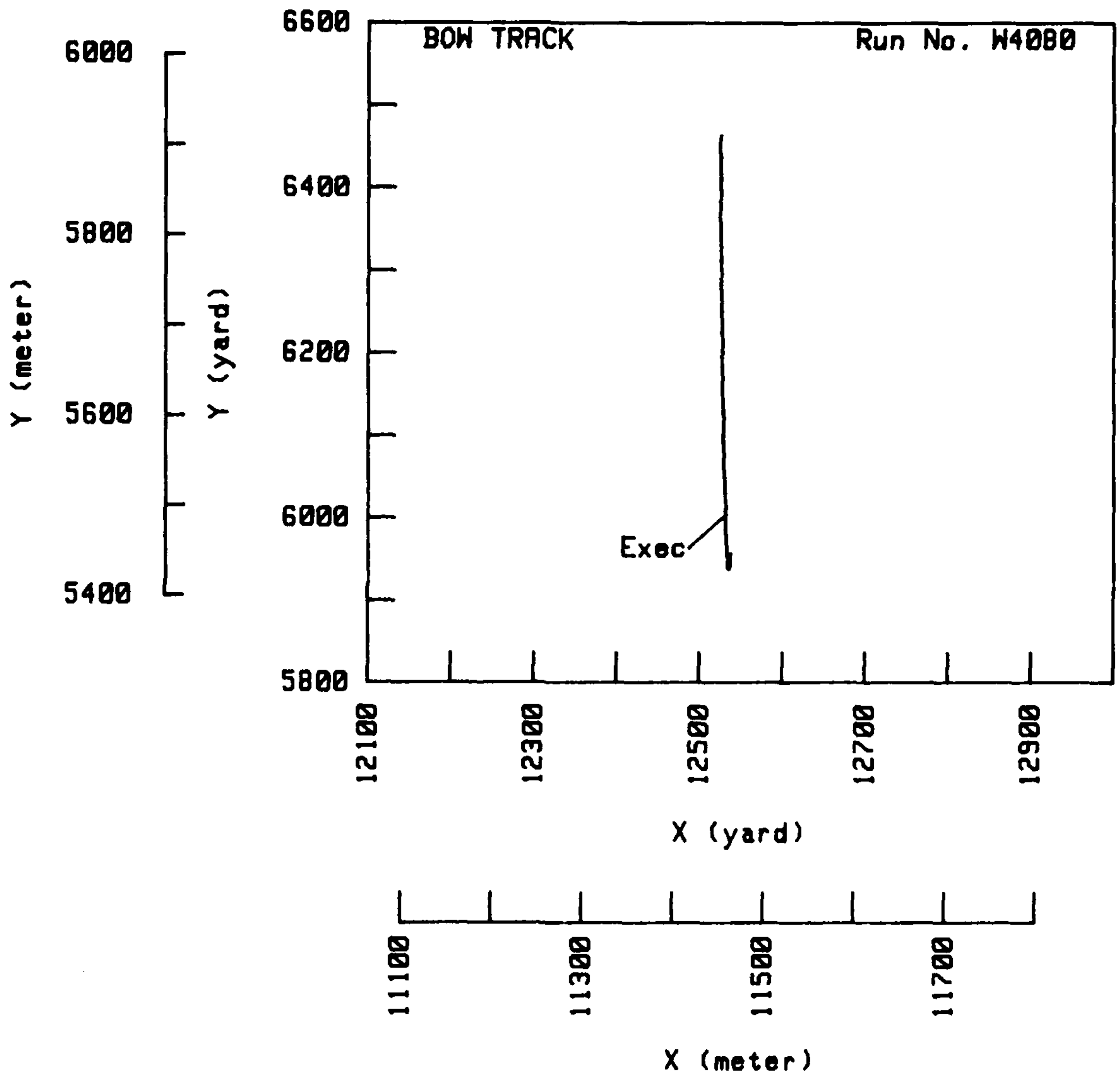


Figure 129 - Position Plot for Full Astern to Full Ahead Acceleration Maneuver (Run W4080)

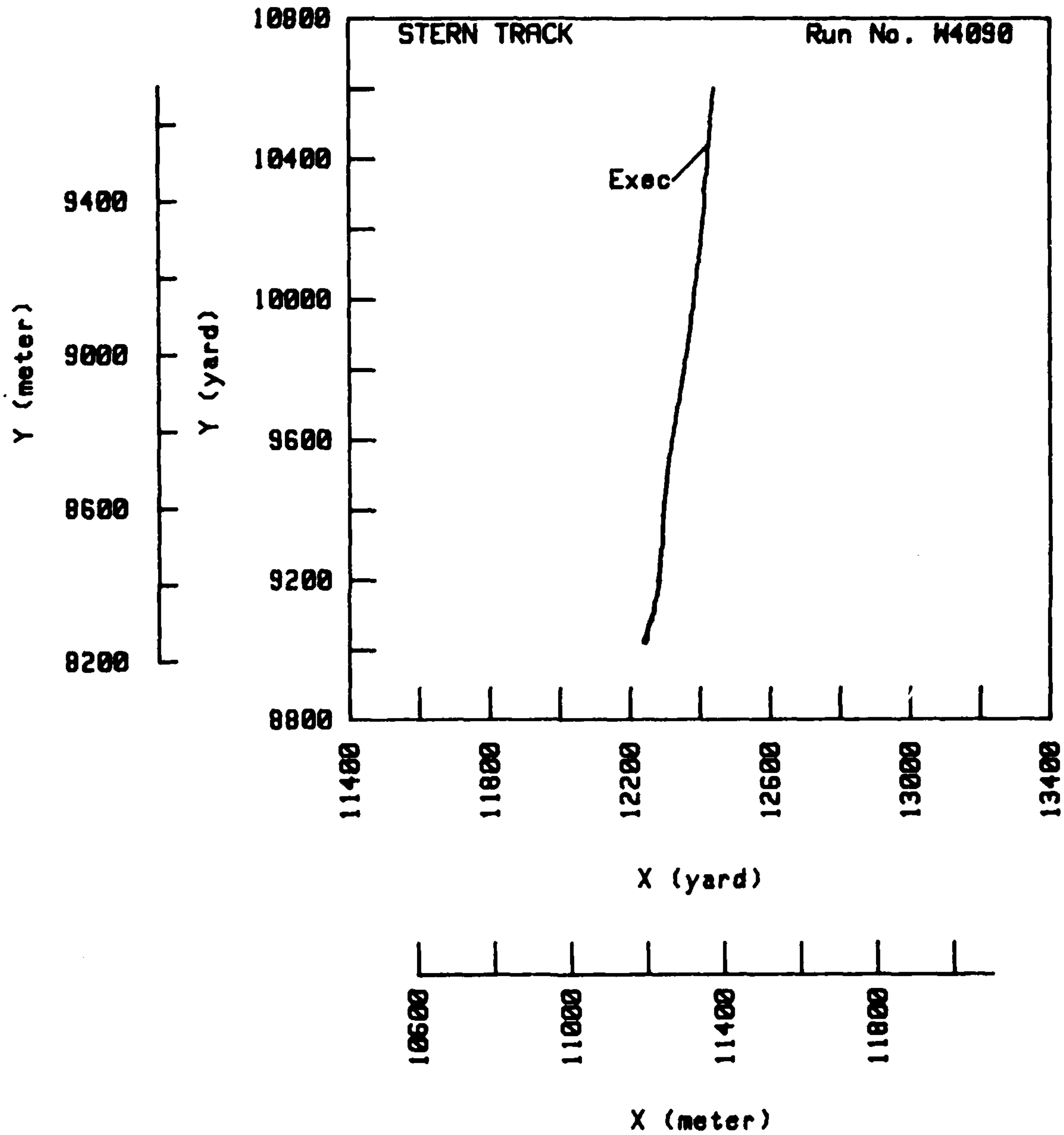


Figure 130 - Position Plot for Full Ahead to All Stop Deceleration Maneuver (Run W4090)

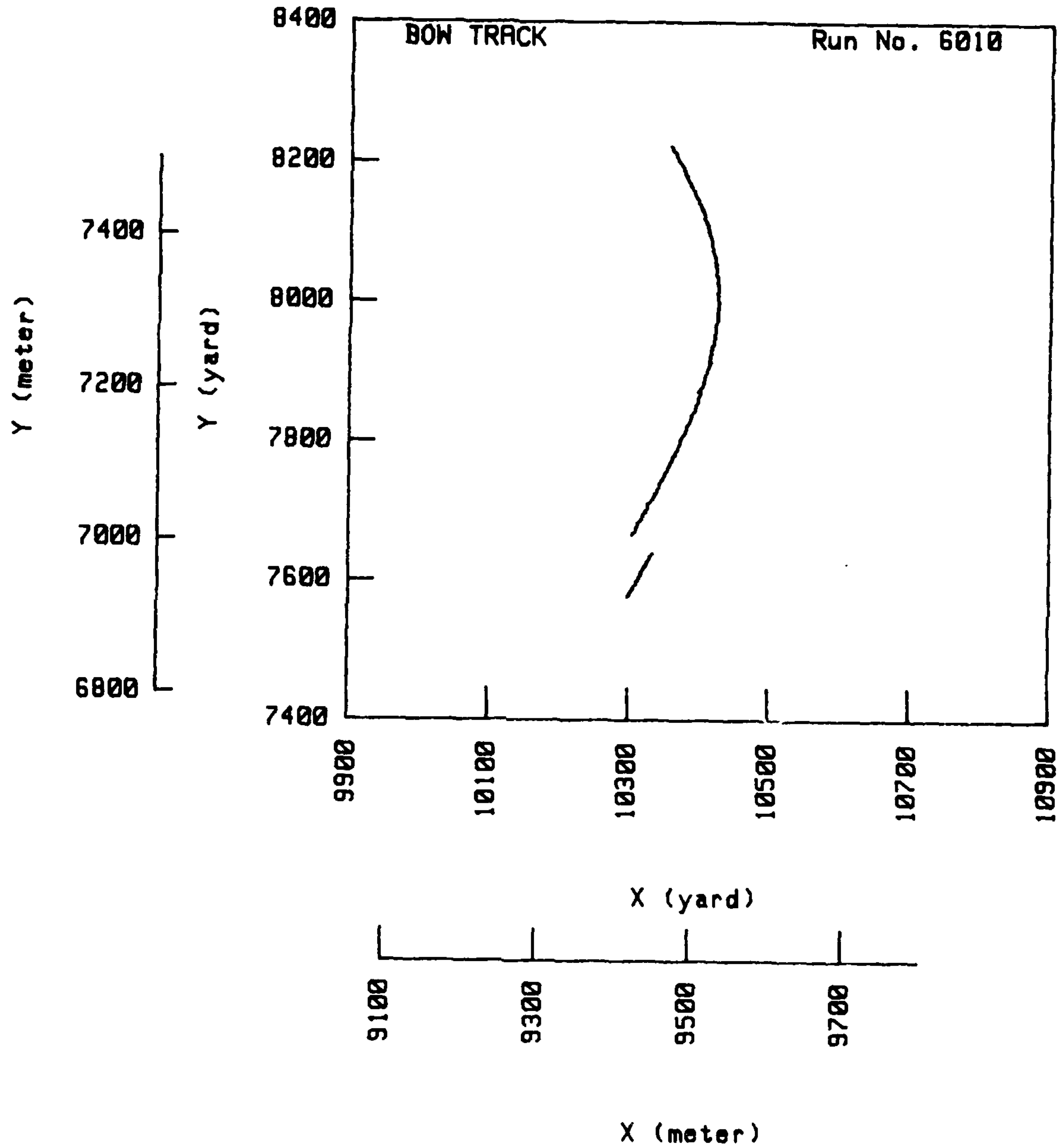


Figure 131 - Position Plot for All Stop to Port Engine Ahead Full, Starboard Engine Astern Full; Twisting Maneuver (Run 6010)

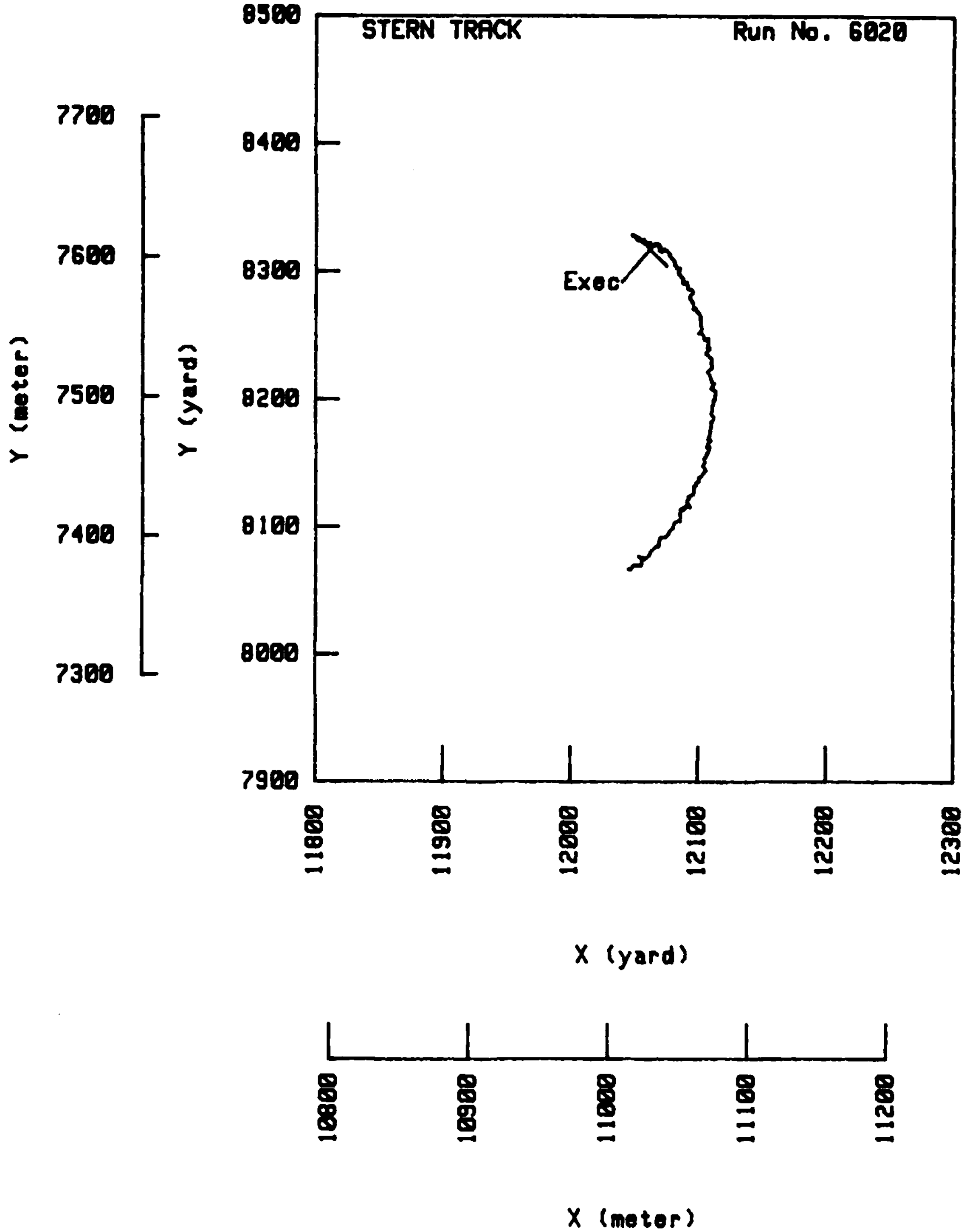


Figure 132 - Position Plot for All Stop to Port Engine Ahead Full, Starboard Engine Astern Full, Left Full Flanking Rudder, Right Full Steering Rudder, Twisting Maneuver (Run 6020)

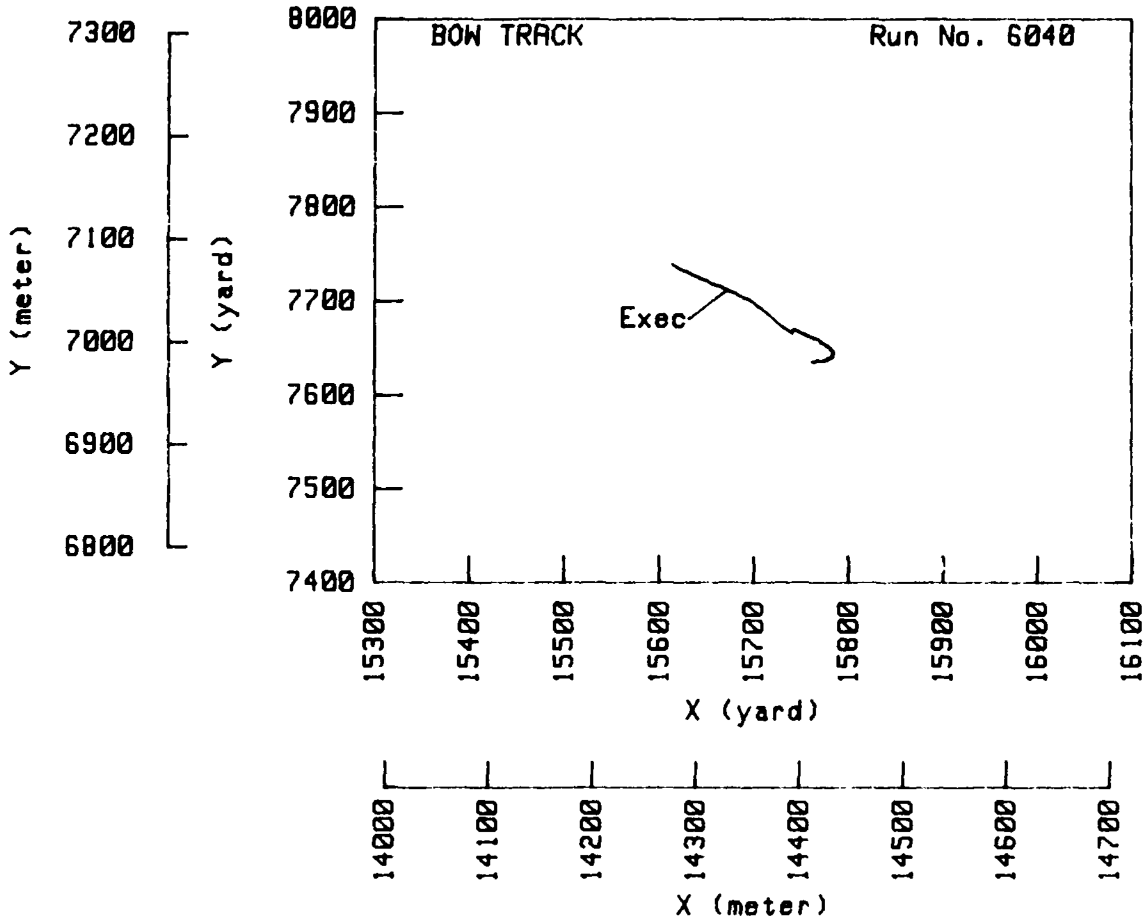


Figure 133 - Position Plot for Astern Full, Right Full Flanking Rudder to Ahead Full, Right Full Flanking Rudder, Checking Turn Maneuver (Run 6040)

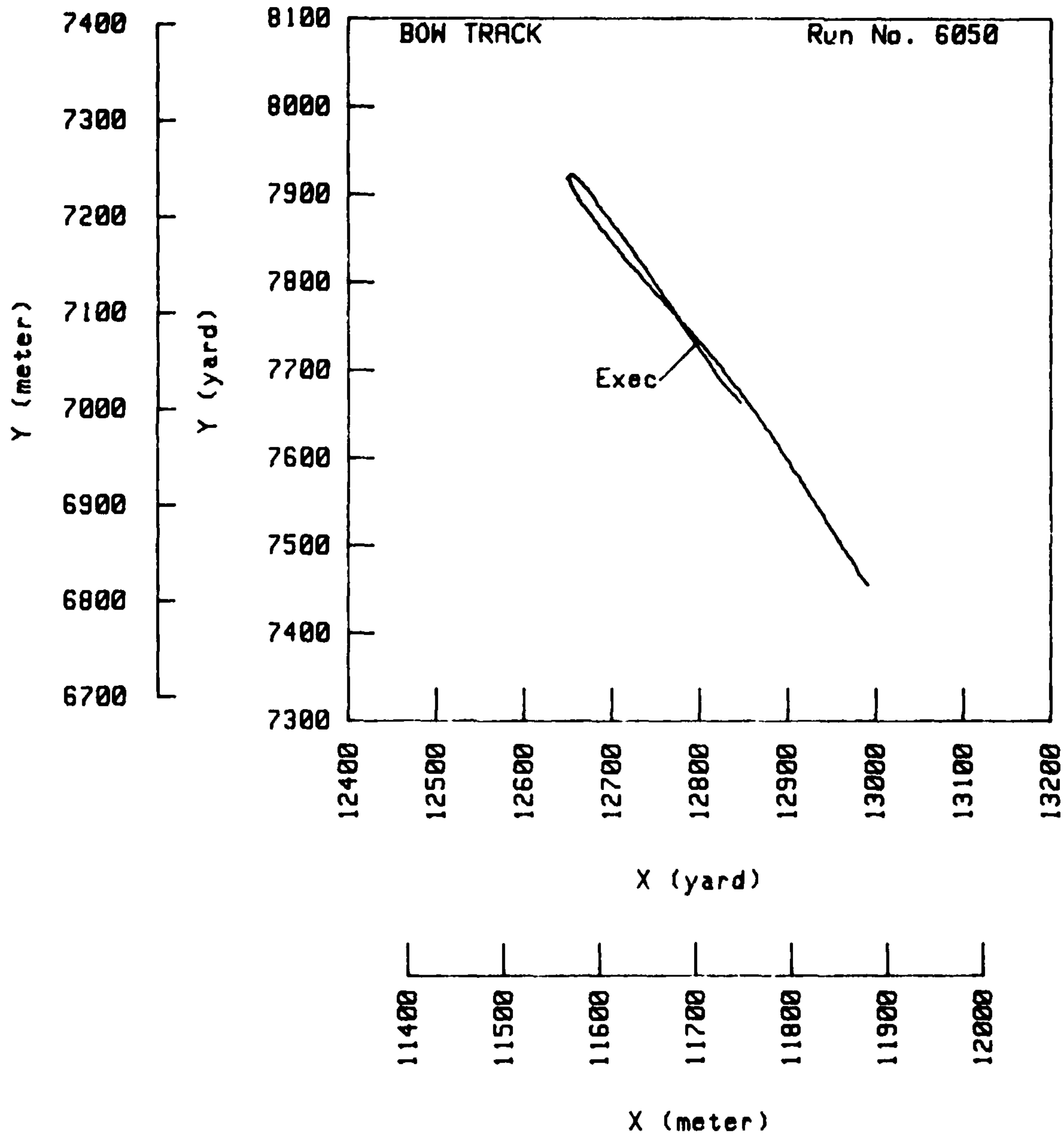


Figure 134 - Position Plot for Ahead Full 10 Degrees Right Steering Rudder to Astern Full, Right Full Flanking Rudder, Checking Turn Maneuver (Run 6050)

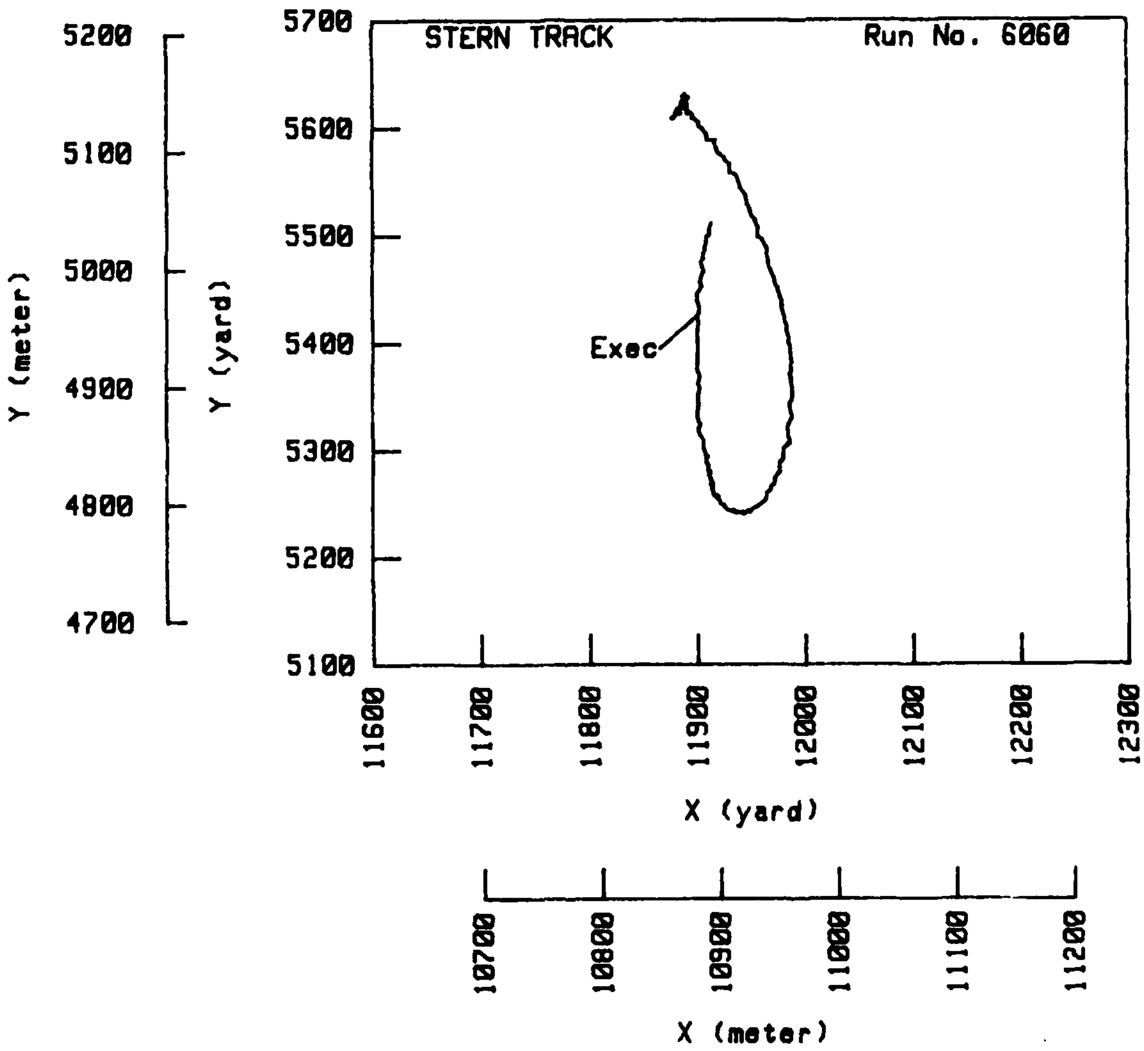


Figure 135 - Position Plot for Astern Full, Right Full Flanking Rudder to Ahead Full, Left Full Steering Rudder, Checking Turn Maneuver (Run 6060)

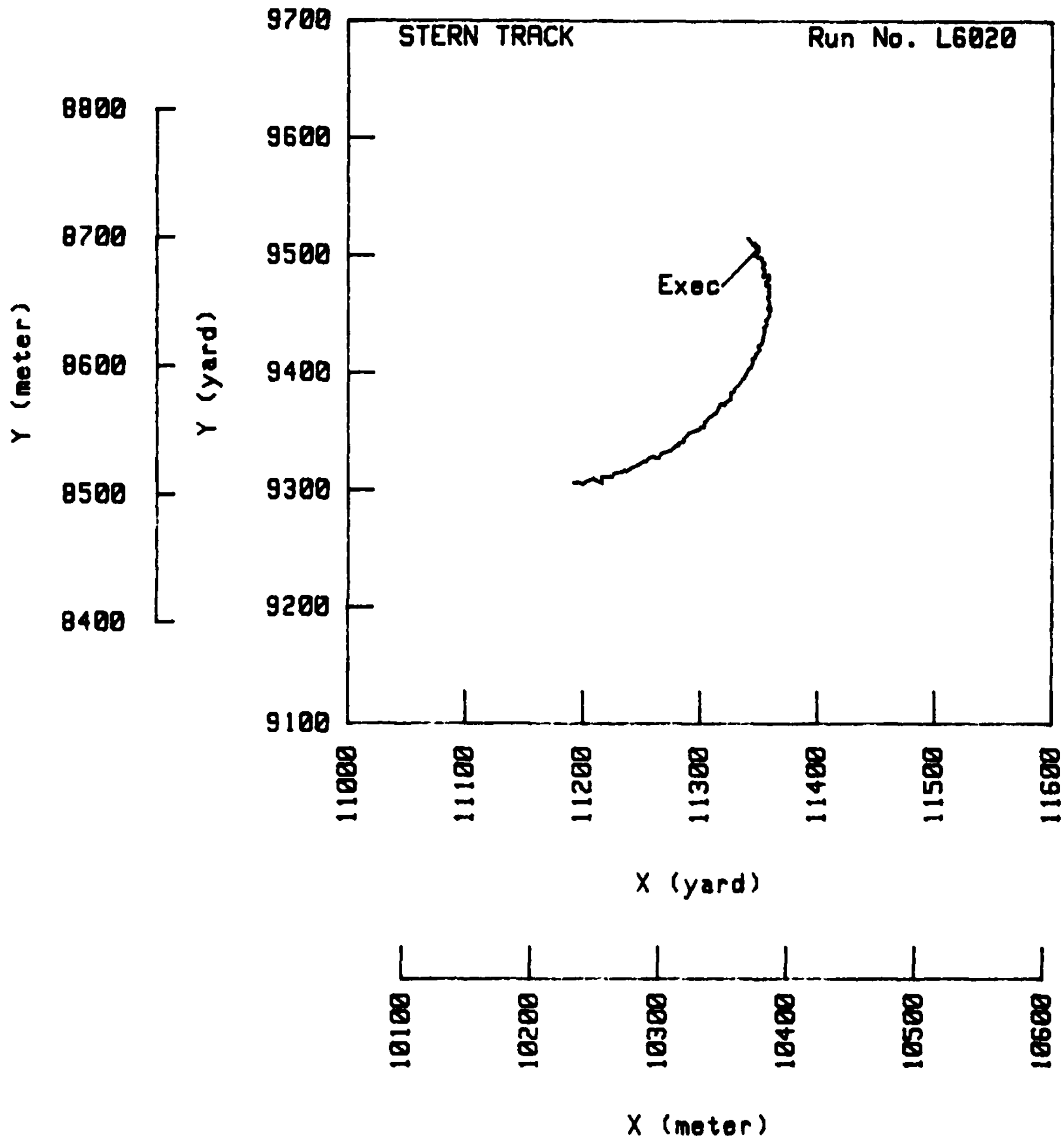


Figure 136 - Position Plot for All Stop to Port Engine Ahead Full, Starboard Engine Astern Full, Right Full Steering Rudder, Left Full Flanking Rudder, Twisting Maneuver (Run L6020)

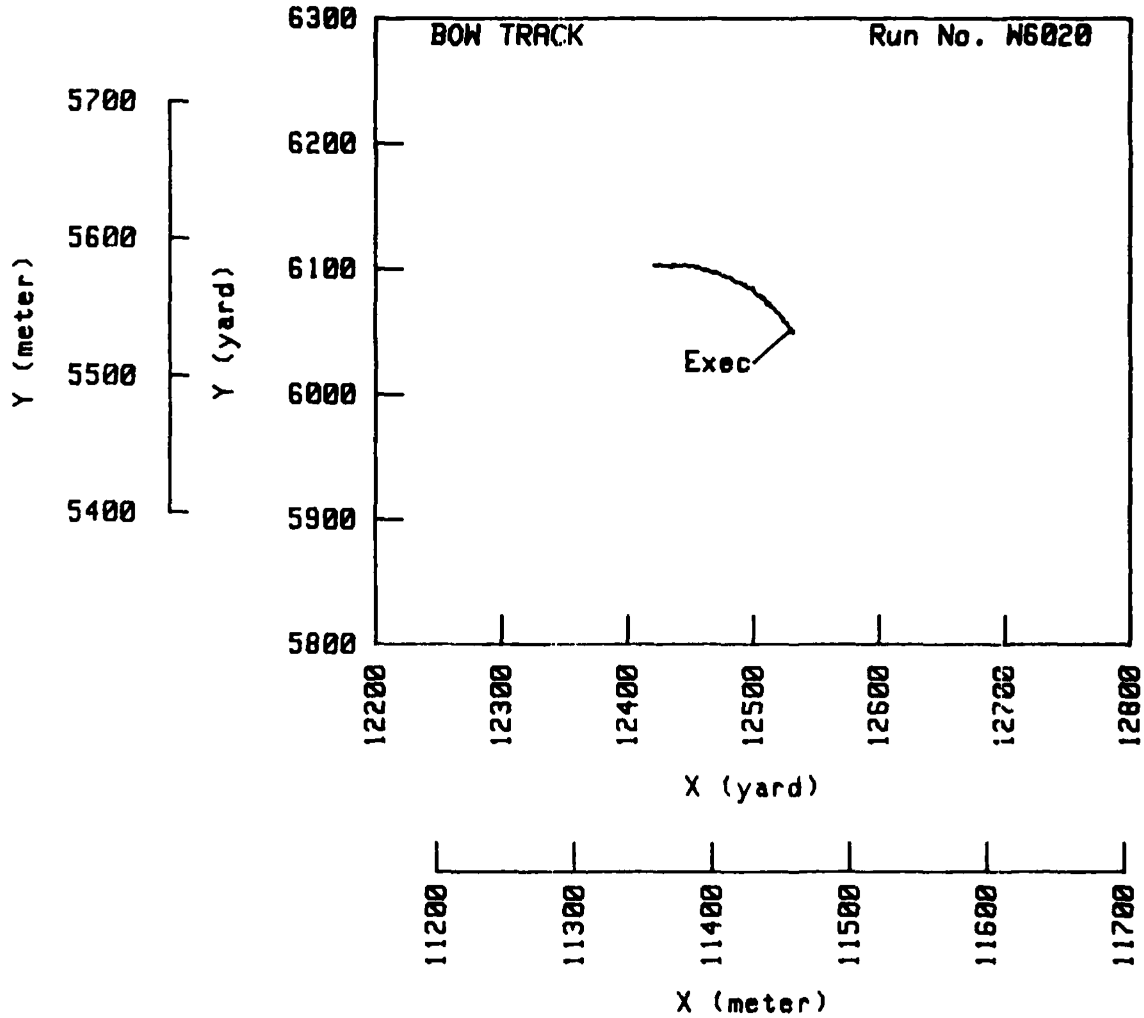


Figure 137 - Position Plot for All Stop to Port Engine Astern Full, Starboard Engine Ahead Full, Port Full Steering Rudder, Right Full Flanking Rudder, Twisting Maneuver (Run W6020)

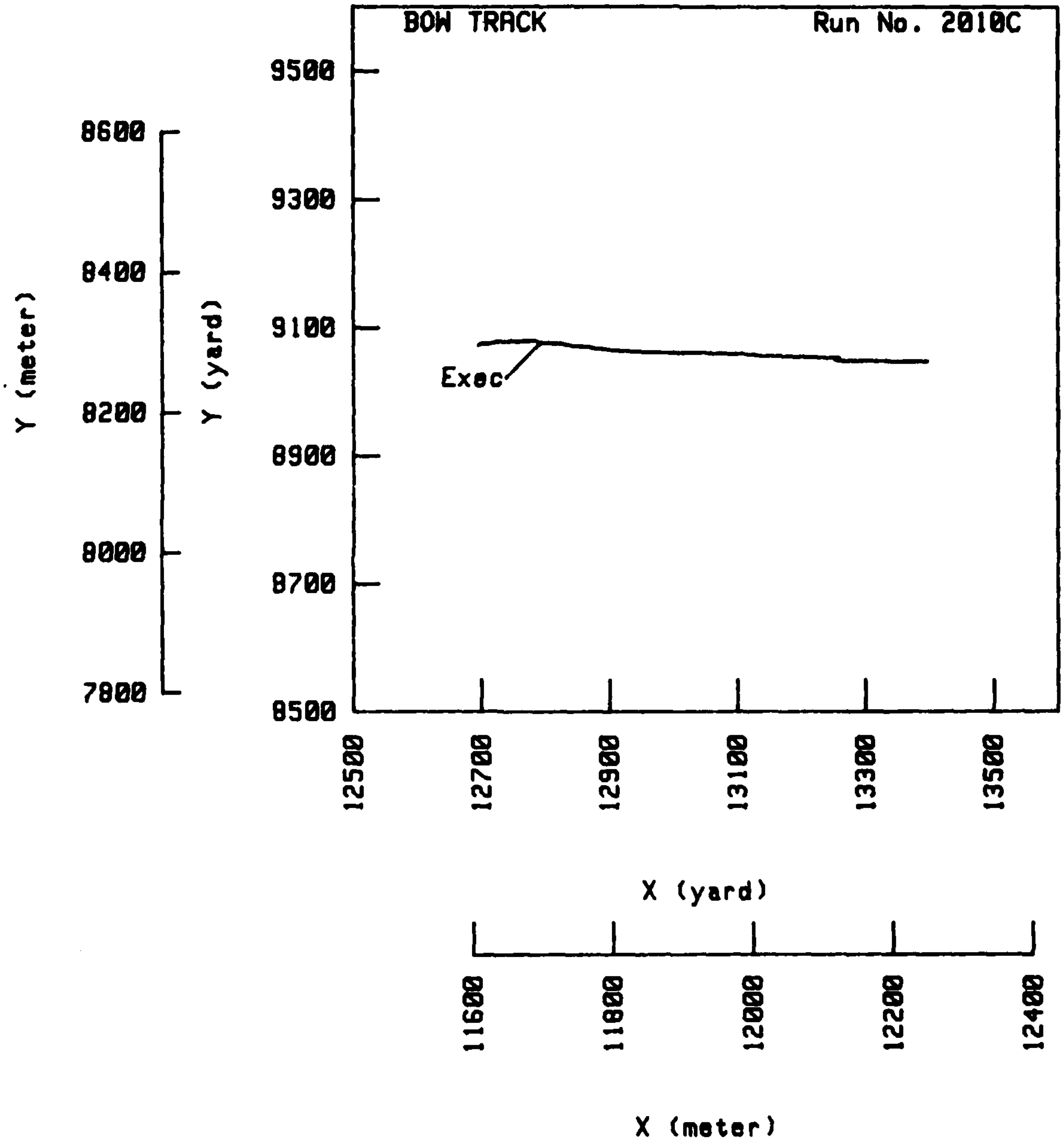


Figure 138 - Position Plot for Checking Maneuver Following Run 2010
(Run 2010C)

TABLE 1 - SIGNIFICANCE OF COEFFICIENTS TO MANEUVERS

Coefficient	Small Amplitude z	Large Amplitude z	Small Amplitude Turn	Large Amplitude Turn	Accelerated Turn	Translational Acceleration
a	1	2	1	3	3	3
X_{vv}	1	2	1	3	3	0
X_{rr}	1	2	1	3	3	0
X_{vr}	1	2	1	3	3	0
b	1	2	1	3	3	3
c	1	2	1	3	3	3
Y_*	3	1	3	1	1	0
Y_v	3	3	3	3	2	0
Y_r	3	3	3	3	2	0
$Y_{\dot{v}}$	3	3	1	1	2	0
$Y_{\dot{r}}$	3	3	1	1	2	0
$Y_{v\|v\|}$	1	2	2	3	3	0
$Y_{r\|v\|}$	1	2	2	3	3	0
$Y_{r\|r\|}$	1	2	2	3	3	0
Y_δ	3	3	3	3	2	0
$Y_{\delta\|\delta\|}$	1	2	2	3	3	0
d,e,f	1	2	1	2	3	0
N_*	3	1	3	1	1	0
N_v	3	3	3	3	2	0
N_r	3	3	3	3	2	0
$N_{\dot{r}}$	3	3	1	1	2	0
$N_{\dot{v}}$	3	3	1	1	2	0
$N_{v\|v\|}$	1	2	2	3	3	0
$N_{r\|v\|}$	1	2	2	3	3	0
$N_{r\|r\|}$	1	2	2	3	3	0
N_δ	3	3	3	3	2	0
$N_{\delta\|\delta\|}$	1	2	2	3	3	0

TABLE 2 - TOW AND BARGE CHARACTERISTICS

Tow:	M/V BENYAURD
Owner:	United States of America Department of the Army (Corps of Engineers)
LOA:	170 feet (51.8 meters)
Beam:	40 feet (12.2 meters)
Draft:	8.5 feet (2.6 meters) at load w.l.
Builder:	Jeffboat, Inc., Jeffersonville, Indiana
Date Launched:	3 February 1979
Hull Number:	78-2423
Main Propulsion Engines:	
Manufacturer:	General Motors
Type:	EMD
Model:	L 12-645-E7 R 12-645-E7
Cylinders:	12
Bhp:	2,150 at 900 rpm
No. of Engines:	2 (one engine per shaft)
Reduction Gears:	
Manufacturer:	Falk
Reduction Ratio:	4.174
Model Numbers:	1635 MRPDC-E 1634 MRSDC-E
Shaft rpm:	216
Propellers:	
Manufacturer:	Avondale Shipyards, New Orleans, Louisiana
Pitch:	74 inches (1.88 meters)
Number of Blades:	5
Diameter:	109 inches (2.77 meters)
Barges:	
Type:	Rake end
Length:	195 feet (59.4 meters)
Width:	35 feet (10.7 meters)
Nominal Draft*:	9 feet (2.7 meters)

*For drafts of each barge while testing refer to Table 3.

TABLE 3 - DRAFT READINGS

LOCATION		DRAFTS							
Barge Number	Barge Position Number	"Baseline" 7/30/85 (ft)	(m)	"Baseline" 7/31/85 (ft)	(m)	"Long" 8/1/85 (ft)	(m)	"Wide" 8/2/85 (ft)	(m)
4430	1	9.2	2.80	8.6	2.62	--	--	--	--
458	2	9.2	2.80	8.8	2.68	--	--	--	--
4406	3	9.0	2.74	8.9	2.71	--	--	--	--
4424	4	9.1	2.77	8.6	2.62	--	--	--	--
4433	5	9.0	2.74	8.8	2.68	8.8	2.68	8.9	2.71
4405	6	9.0	2.74	8.8	2.68	8.8	2.68	8.9	2.71
4407	7	9.5	2.90	8.4	2.56	--	--	--	--
426	8	9.0	2.74	8.6	2.62	9.0	2.74	9.0	2.74
732	9	8.9	2.71	8.8	2.68	9.1	2.77	9.0	2.74
4419	10	8.9	2.71	9.1	2.77	--	--	--	--
4434	11	9.0	2.74	9.0	2.74	8.9	2.71	8.9	2.71
4303	12	8.8	2.68	8.6	2.62	8.7	2.62	8.8	2.68
733	13	9.4	2.86	9.0	2.74	--	--	--	--
4443	14	8.6	2.62	8.9	2.71	--	--	--	--
559	15	9.2	2.80	8.9	2.71	--	--	--	--
Towboat									
Port Bow		--	--	--	--	9.0	2.74	9.0	2.74
Starboard Bow		--	--	--	--	8.8	2.68	8.8	2.68
Port Stern		9.5	2.90	--	--	9.5	2.90	9.8	2.99
Starboard Stern		9.5	2.90	--	--	9.5	2.90	9.5	2.90
Specific Gravity		1.0005		--		1.0005		1.0005	
Temperature, °F (°C)		84 (28.9)		--		84 (28.9)		84 (28.9)	

TABLE 4 - SUMMARY OF CALIBRATION RUNS

Run No.	Date	Falcon Speed (knot)	Starboard RPM	Port RPM	Average RPM	Relative Wind Speed (knot)	Relative Wind Direction (deg)	Heading (deg)
1040	29 Jul	4.9	171.8	172.9	172.4	4.0	235	89
1050	29 Jul	4.9	172.2	172.4	172.3	11.5	33	270
Average		4.9			172.4			
1010	29 Jul	5.8	199.4	197.6	198.5	12.3	30	270
1020	29 Jul	5.8	197.3	198.8	198.0	2.9	287	90
Average		5.8			198.2			
1070*	29 Jul	3.0	211.4	208.2	209.8	7.4	223	89
1080*	29 Jul	2.9	210.4	208.4	209.4	2.2	72	269
Average		2.9			209.6			
L1040	1 Aug	3.7	102.2	101.2	101.7	11.8	22	276
L1050	1 Aug	3.5	100.9	100.7	100.8	5.2	224	80
Average		3.6			101.2			
L1010	1 Aug	6.4	179.7	181.1	180.4	13.2	15	280
L1020	1 Aug	6.7	181.9	182.0	182.0	2.4	242	80
Average		6.6			181.2			
L1065*	1 Aug	1.9	100.6	101.1	100.8	3.9	9	280
L1066*	1 Aug	1.9	102.0	100.4	101.2	13.4	271	78
Average		1.9			101.0			
L1070*	1 Aug	3.5	180.1	179.3	179.7	2.4	28	280
W1040	2 Aug	3.0	89.6	89.3	89.4	1.4	52	0
W1050	2 Aug	3.0	89.5	88.7	89.1	3.9	22	181
Average		3.0			89.2			
W1010	2 Aug	4.9	145.7	145.5	145.6	2.9	33	0
W1020	2 Aug	4.8	145.4	145.2	145.3	5.4	20	181
Average		4.9			145.4			

*Astern Runs

TABLE 4 (Continued)

Run No.	Date	Falcon Speed (knot)	Starboard RPM	Port RPM	Average RPM	Relative Wind Speed (knot)	Relative Wind Direction (deg)	Heading (deg)
W1065*	2 Aug	1.4	88.0	87.1	87.6	3.8	187	181
W1066*	2 Aug	1.5	87.8	87.2	87.5	0.2	17	1
Average		1.4			87.6			
W1070*	2 Aug	2.6	145.7	145.1	145.4	5.0	190	180
W1080*	2 Aug	2.6	145.0	145.3	145.2	3.4	61	0
Average		2.6			145.3			

*Astern Runs

TABLE 5 - SUMMARY OF TURNING MANEUVERS FOR BASELINE TOW CONFIGURATION

Run No.	Date	Run Description	Rudder Angle (deg)	Approach Heading (deg)	Approach Speed (knot)	Relative Wind Speed (knot)	Relative Wind Direction (deg)	Advance (yd)	Advance (m)	Transfer (yd)	Transfer (m)	Tactical Diameter (yd)	Tactical Diameter (m)
2000	29 Jul	45° Ahead Turn	35R	127.9	3.7	3.8	085	--	--	--	--	--	--
2002	29 Jul	[1]Continuation of 2000	35R	15.7	--	0.2	287	--	--	--	--	--	--
2010	30 Jul	[2]Ahead Turn	35R	270.9	5.7	12.7	035	750	686	390	357	--	--
2020	30 Jul	Ahead Turn	25L	89.2	5.7	3.5	289	900	823	555	507	--	--
2040	30 Jul	Ahead Turn	15R	91.1	5.8	5.0	277	1275	1166	870	796	--	--
2050	29 Jul	540° Circle	35L	271.4	5.7	12.2	341	715	654	375	343	925	846
2120	30 Jul	180° Astern Turn	35R	270.5	3.6	6.0	039	855	782	560	512	1185	1084
2130	29 Jul	360° Astern Circle	35R	270.1	3.1	8.0	300	770	704	545	498	1145	1047
2140	30 Jul	Astern Turn	20R	89.9	3.3	17.0	134	1145	1047	855	782	--	--
2141	30 Jul	[1]Continuation of 2140	20R	263.0	--	--	--	--	--	--	--	--	--
2090	29 Jul	180° Ahead Turn	35L	272.1	5.8	10.4	339	855	782	400	366	915	837
2100	29 Jul	Ahead Turn	35L	82.3	3.7	8.9	100	645	590	385	352	910	832
2110	29 Jul	Coasting	35R	271.0	5.6	11.2	323	--	--	--	--	--	--
2115	29 Jul	Coasting	35L	271.0	5.9	12.3	333	--	--	--	--	--	--
2117	30 Jul	Accelerating Turn	35L	0.2	All Stop	6.8	323	--	--	--	--	--	--
2150	31 Jul	Astern Turn	35R	257.8	3.0	11.0	054	945	864	455	416	--	--
2160	30 Jul	Astern Turn	35L	270.6	1.7	4.1	066	680	622	585	535	--	--
2180	31 Jul	Accelerating Turn	35R	182.1	All Stop	14.6	118	--	--	--	--	--	--

[1]No Execute mark

[2]Track shift prior to Execute

TABLE 6 - SUMMARY OF TURNING MANEUVERS FOR TOW CONFIGURATIONS L AND W

Run No.	Date	Run Description	Rudder Angle (deg)	Approach Heading (deg)	Approach Speed (knot)	Relative Wind Speed (knot)	Relative Wind Direction (deg)	Advance (yd)	Advance (m)	Transfer (yd)	Transfer (m)	Tactical Diameter (yd)	Tactical Diameter (m)
[illegible]	[illegible]	[1]Ahead Turn	35R	180.7	2.8	6.1	074	375	343	330	302	--	--
L2010	1 Aug	Ahead Turn	35L	296.2	5.3	25.1	138	540	494	275	251	--	--
[illegible]	1 Aug	Ahead Turn	35L	266.9	5.3	10.5	338	485	443	275	251	--	--
L2040	1 Aug	Ahead Turn	20R	30.9	5.2	4.7	131	700	640	420	384	--	--
L2120	1 Aug	[1]Astern Turn	35L	78.0	1.9	9.0	217	590	539	225	206	--	--
L2130	1 Aug	Astern Turn	35L	164.1	2.7	7.0	149	460	421	300	274	--	--
L2140	1 Aug	Astern Turn	10R	194.7	2.9	4.8	065	1030	942	715	654	--	--
L2116	1 Aug	Accelerating Turn	35R	94.5	All Stop	11.0	142	--	--	--	--	--	--
W2000	2 Aug	Ahead Turn	35L	25.8	2.8	9.4	026	390	357	180	165	--	--
W2010	2 Aug	540° Circle	35R	0.2	5.3	10.8	048	400	366	130	119	430	393
W2040	2 Aug	Ahead Turn	20R	34.8	5.2	10.6	056	540	494	275	251	--	--
W2120	2 Aug	Astern Turn	35R	135.9	1.5	12.1	267	540	494	130	119	--	--
W2130	2 Aug	Astern Turn	35L	145.9	2.9	1.1	343	250	229	145	133	--	--
W2140	2 Aug	[1]Astern Turn	20L	55.6	2.9	1.3	356	615	562	120	110	--	--
W2116	2 Aug	Accelerating Turn	35L	207.0	All Stop	7.1	264	76	72	193	176	--	--

[1]Track shift prior to Execute

TABLE [illegible] - SUMMARY OF HORIZONTAL OVERSHOOT MANEUVERS FOR BASELINE TOW CONFIGURATION

Run No.	3010	3020	3100	3030	3040	3060	3070	3120	3130	3150	3160
Approach Speed (knot)	5.6	5.6	2.8	5.8	3.6	2.8	5.5	2.7	1.5	1.8	3.1
Rudder Angle at 1st Execute (deg)	10R	20R	10L	10R	10R	20R	20L	10R	10R	20L	20R
Course Change (deg)	10	20	10	10	10	20	20	10	10	20	20
Time from 1st to 2nd Execute (s)	122	135	535	220	150	152	205	660	360	325	600
Time from 1st to 3rd Execute (s)	430	450	1240	595	395	480	660	--	1135	1025	--
Time from 1st to 4th Execute (s)	704	755	1839	1005	695	800	1100	--	1725	1650	--
Time from 1st to 5th Execute (s)	1021	1070	2482	--	--	--	--	--	--	--	--
Overshoot after 2nd Execute (deg)	2.5	3.5	3.5	2.0	1.5	3.0	4.0	1.0	2.0	3.5	2.0
Overshoot after 3rd Execute (deg)	2.5	3.5	2.0	3.0	3.0	3.0	2.5	--	1.0	3.5	
Overshoot after 4th Execute (deg)	4.0	3.0	2.5	2.5	2.5	3.0	3.0	--	2.5	3.5	--
Overshoot after 5th Execute (deg)	2.5	3.5	1.5	--	--	--	--	--	--	--	--
Overshoot after 6th Execute (deg)	--	--	--	--	--	--	--	--	--	--	--
Reach (s)	336	342	1100	485	320	362	500	--	960	825	1385
Period (s)	582	614	1304	785	545	648	890	--	1365	1325	--

TABLE 8 - SUMMARY OF HORIZONTAL OVERSHOOT MANEUVERS FOR TOW CONFIGURATIONS L AND W

Run No.	L3010	L3011	L3100	W3010	W3021	W3100	W3101	W3105
Approach Speed (knot)	5.3	5.0	2.7	5.0	5.0	2.7	2.8	2.9
Rudder Angle at 1st Execite (deg)	10R	10R	10L	10R	20R	10L	10R	20L
Course Change (deg)	10	10	10	10	20	10	10	10
Time from 1st to 2nd Execute (s)	94	100	270	65	72	180	97	95
Time from 1st to 3rd Execute (s)	360	290	785	225	245	--	920	475
Time from 1st to 4th Execute (s)	--	520	1265	373	401	--	--	1070
Time from 1st to 5th Execute (s)	--	710	--	550	--	--	--	--
Overshoot after 2nd Execute (deg)	2.5	2.0	3.0	2.5	5.0	--	32	8.5
Overshoot after 3rd Execute (deg)	2.0	2.5	4.0	2.0	4.0	--	--	40
Overshoot after 4th Execute (deg)	--	2.0	5.0	3.0	4.0	--	--	50
Overshoot after 5th Execute (deg)	--	3.0	--	2.0	--	--	--	--
Overshoot after 6th Execute (deg)	--	--	--	2.5	--	--	--	--
Reach (s)	260	237	675	180	175	--	885	445
Period (s)	--	420	995	308	330	--	--	975

APPENDIX A

TRIAL SITE DESCRIPTION

The Falcon 484 positioning system manufactured by Motorola, Inc. provided the means by which the bow and the stern of the tow/barge configuration were tracked during the maneuvering trials. The Falcon is a pulse-radar system which has a nominal range of 20 nautical miles, provided line-of-sight is maintained. The system is normally used to determine a two-range position via a process called trilateration. This is a standard survey technique to determine position when the lengths of all three sides of a triangle are known. In order to improve the tracking accuracy of the Falcon system, as well as to incorporate backup reference stations, it was decided to establish four, vice the normal two, reference stations. The Falcon system used the method of least squares to calculate position when three or four reference sites are used. The use of more than two sites will generally yield more accurate and reliable positioning due to the added weighting provided by the redundant range measurement.

The proposed trial site provided an excellent opportunity to establish four reference stations since Lake Pontchartrain is approximately 22 miles in diameter and is bisected by Lake Pontchartrain Causeway. Plans were therefore made to install reference transponders at causeway crossover number six, crossover number two, Lacombe Bayou on the northeast shore, and Lincoln Beach on the southeast shore. A cartesian coordinate system was subsequently developed based on a local survey by DTNSRDC personnel using a Loran C navigation system and the Falcon 484 positioning system. The three by four mile rectangle shown in Figure 139 represents the boundaries of the trial site. The coordinates used for each reference station are shown in Table 9. Two sets of coordinates are listed in Table 9 for the reference station located at Lincoln Beach. This reference station was relocated after two days of testing due to a concern for the level of security at the initial site.

The placement of each reference site was determined in accordance with selection criteria published by Motorola.[4] The height of each reference transponder was such that line-of-sight could be maintained with the towboat R/T's, and range dropout due to vertical multipath could be avoided.

Transponder placement along the causeway and the shore were also in accordance with standard survey techniques to insure that acceptable geometry would be maintained throughout the trials. Acceptable geometry generally means that the angle of intersection between range lines is between 30 degrees and 150 degrees.

The size of the test site was found to be adequate for the trials as little difficulty was experienced in keeping the tow/barge configuration within the designated boundaries.

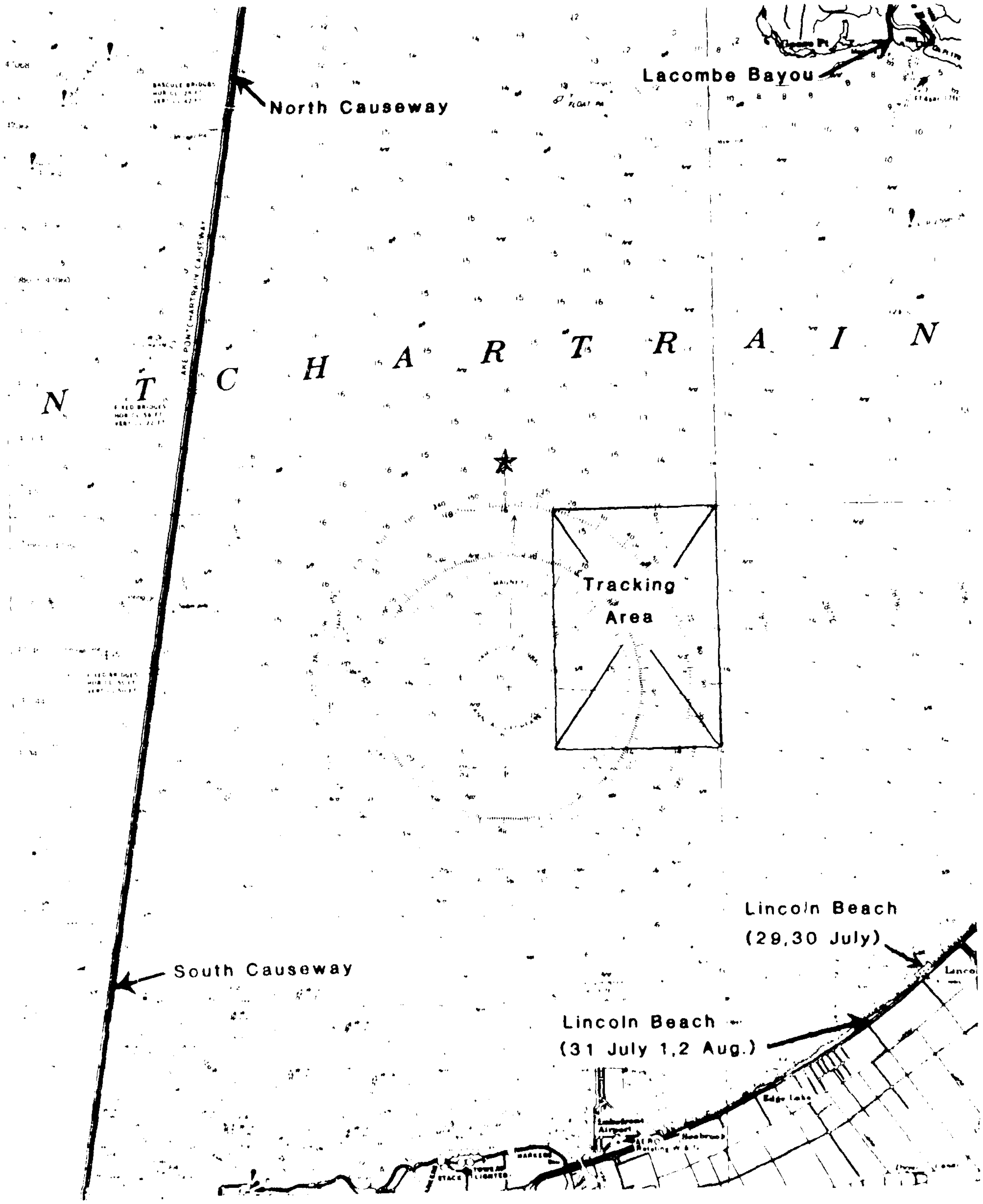


Figure 139 - Trial Site and Reference Stations

TABLE 9 - REFERENCE STATION COORDINATES

Designation	Range Designation	X (yards)	X (meters)	Y (yards)	Y (meters)
North Causeway	1	3,464	3,167	22,820	20,867
Lacombe Bayou	2	19,860	18,160	23,277	21,284
South Causeway	3	0	0	0	0
Lincoln Beach (29,30 July)	4	20,308	18,570	78	71
Lincoln Beach (31 July, 1,2 Aug)	4	18,875	17,259	-1,307	-1,195

APPENDIX B

TRIAL INSTRUMENTATION

GENERAL

The location of the data acquisition center, the mounting methods for the required transducers and antennas, and cable routes were determined during an inspection of BENYAURD on 20 May 1985. The electronic equipment room, located directly below the pilot house, was selected as the data acquisition center. This room is normally unmanned, large enough for the recording and data analysis equipment, and air conditioned thus reducing the probability of equipment failure. The proximity of the electronic equipment room to the Pilot House also facilitated taking track plots and other data to the Project Manager for examination.

TRANSDUCERS AND SIGNAL CONDITIONING

Movements of the steering and flanking rudders were monitored via synchro transmitters coupled directly to the rudder stock. The outputs from the synchro transmitter were converted to direct current voltages by means of a solid-state synchro to analog (S/A) converter. The resulting voltage was then routed to the electronic equipment room. Calibration of the rudder angle indicators was accomplished by deflecting each rudder left and right through various rudder angles as indicated by index marks on the rudder stock in after steering.

Port and starboard shaft RPM were measured by means of an infrared light sensor mounted adjacent to 60 strips of tape which reflect infrared light. Thus for each shaft rotation, the infrared sensor produces 60 pulses which were then converted to a direct current voltage. Calibration is accomplished by adjusting the output of the frequency-to-voltage converter to a voltage proportional to a known frequency. The voltages representative of shaft RPM (positive for both ahead and astern shaft rotation) were then routed to the electronic equipment room. Remote RPM indicators were also installed in the pilot house for use during the trials.

Towboat heading was measured via a MK 27 MOD1 gyro compass provided by the U. S. Coast Guard. The master compass was mounted to the deck in the electronic equipment room. The synchro output of the gyro compass was

converted to a direct current voltage by a solid-state S/A converter. Proper operation of the gyro compass was verified by rotating the base of the compass before it was bolted to the deck.

Turning rate of the BENYAURD was measured with a rate gyro installed in the electronic equipment room for the duration of the trial. The rate gyro has a full scale of plus or minus three degrees per second with a corresponding output voltage between plus and minus ten volts.

Wind speed and direction were measured via a DTNSRDC-owned anemometer attached to a 40-foot high mast which was mounted on a forward barge. The anemometer was mounted on the barge and not the towboat to avoid possible wind flow interference from the towboat superstructure. The anemometer excitation and output cables were routed along the decks of the barges in the tow. Quick-disconnect connectors were provided along the cable route to permit the tow to be separated and rearranged when necessary. The speed output of the anemometer was calibrated at the National Bureau of Standards in Gaithersburg, Maryland and the direction output was calibrated by rotating the anemometer housing by known angles of deflection prior to raising the mast.

A Falcon 484 tracking system was used during the trials in order to determine the position of both the bow and the stern of the towboat/barge configuration. In order to track the position of the BENYAURD, the flagstaff above the pilot house was replaced by a mast equipped with a receiver/transmitter (R/T). The R/T was then electrically connected to a tracking console located in the electronic equipment room. Upon command from the tracking console, the R/T interrogates or measures the straight-line distance to two or more reference stations located at fixed points, typically on shore. Knowledge of the geometry of the reference stations then permits the determination of the R/T location relative to an X/Y coordinate system. This technique is more fully described in Appendix A.

In order to insure that the heading of the tow configuration was known at all times, a second R/T unit was installed on a 40-foot tall Texas Tower mounted on a forward barge in the tow configuration. The second R/T, however, could not be directly connected to a tracking console in the electronics equipment room due to the distance of approximately 700 feet between the R/T and the towboat. The excessive distance required that the second tracking

console be located on an adjacent barge. A metal shed, equipped with a window air conditioning unit, was therefore installed on a forward barge to house the tracking console and a bus extender unit. The parallel data output from the console was converted to serial form by the bus extender (remote) and routed to a similar bus extender (local) located in the electronic equipment room. The local extender then converted the serial data back to parallel form for input to the computer system. A block diagram of the overall instrumentation system is shown in Figure 140.

Two electromagnetic water current meters were installed once the tow was configured at the trial site on Lake Pontchartrain. The Marsh-McBirney current meters, which provide speed data for both the X and Y components of water velocity, were attached to wooden beams and mounted between adjacent barges.

The flow probes were observed to be occasionally twisted or rotated relative to the original alignment due to the resultant forces on the supporting beams. Shifts in the X and Y velocity outputs noted during the trials are likely attributable to probe rotation.

Data from these instruments are not presented in this report but are included in the data on the previously mentioned nine-track magnetic tape.

RECORDING INSTRUMENTATION

The scan rates and the number of data channels specified for these trials resulted in the selection of a Hewlett-Packard 9826 Desktop Computer as the controller for the data acquisition system. The 9826 computer is a 16 bit machine with a monochrome CRT, an integrated 5¼ inch flexible disk drive, and can support up to 2.05M bytes of internal RAM.

For the subject trials, the 9826 computer was programmed in BASIC language, and the data from each run was stored on the internal disk drive. An array size of 1800 samples by 40 channels was selected, thus requiring 144K bytes of RAM to store the data from each run (1800 samples x 40 channels x 2 bytes per sample). Since data was stored on the disk only at the end of each run, the system could collect data for one hour at a sample rate of once every two seconds (1800 samples x 2 seconds per sample x 1 hour per 60 seconds).

Selected data channels were displayed during each run to verify that (1) the proper test conditions had been achieved and (2) the data acquisition system was functioning properly. Following the completion of each run, all measurements were recorded as voltages and a run summary was printed in engineering units. Additional information concerning the manner in which the data was stored is presented in Appendix C.

All analog data was input to the computer via a Hewlett-Packard 2240A Measurement and Control Processor. The processor is capable of converting analog voltages between ±10 volts to digital form with an accuracy of ±5 millivolts.

Position data was input directly from the tracking consoles to the computer using a high speed transfer statement. This arrangement was necessary as each tracking console was "free running" and provided a large amount of position data at one second intervals.

The majority of the instrumentation performed satisfactorily during the maneuvering trials. An exception to this is the rate gyro which failed during the middle of the trials. No attempts were made to repair or replace the gyro since the gyro compass was operating properly and provided an alternate means of determining rate of change of heading. Occasional difficulties were experienced with shaft speed, apparently due to local vibration. The only other problem, occasional shifts in the tracking data, is described under Trial Results.

Table 10 lists the probable measurement accuracies achieved during the trials.

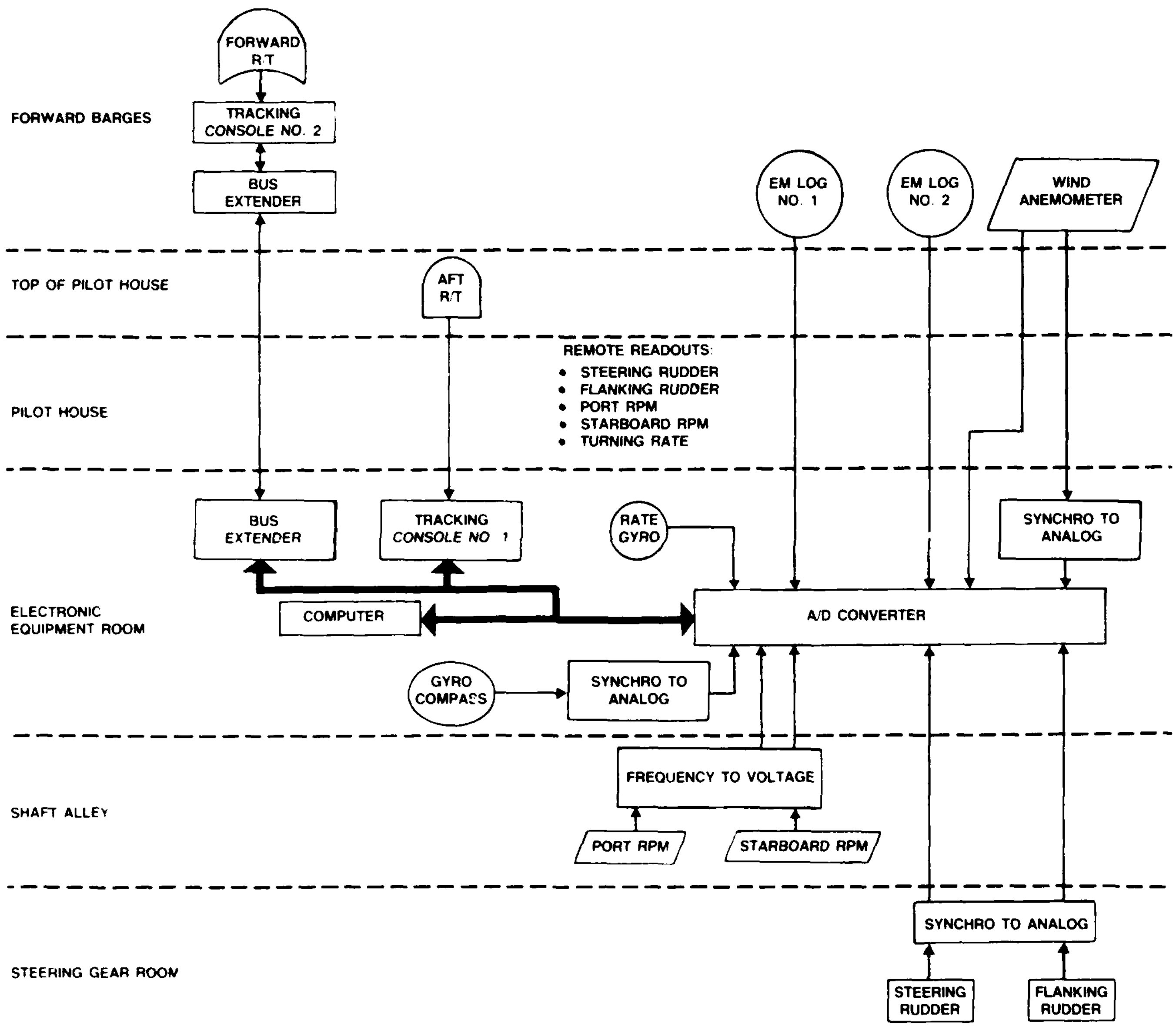


Figure 140 - Instrumentation Block Diagram

TABLE 10 - PROBABLE MEASUREMENT ACCURACIES

Measurement	Accuracy
Rudder Angle	±0.25 deg
Shaft RPM	±0.5 rpm
Relative Heading	±0.25 deg
Turning Rate	±0.05 deg/sec
Wind Speed	±0.5 knots
Wind Direction	±1.0 deg (±5 deg alignment accuracy)

APPENDIX C

DATA TAPE PARTICULARS

Data obtained during maneuvering trials on M/V BENYAURD and its various tows have been transferred to nine-track magnetic tapes to facilitate future data analysis. Systems identification analysis will be performed in order to determine the hydrodynamic coefficients of each tow configuration. Table 11 identifies the measurements recorded on the tape as well as the formatting particulars. Table 12 provides a chronological list of the runs conducted.

TABLE 11 - DATA TAPE PARTICULARS

FORMAT ASC II, 1600 BPI

Header

X, 5A, 2X, 8A, 2X, 3D, 2X, 4D, 2X, 8A

Data

4D, X, 4(6D,X), 4D.DD,X, 2(3D.DD,X), 2(4D.DD,X), DD.3D, X, 3D.DD, X, 3D.D., X, 4(3D.3D,X), 8(6D, X), 3(3D, X)

Header

Word	Channel
1	Run # (string)
2	Date (string)
3	Execute Pt. (numeric)
4	Last Pt. (numeric)
5	Execute Time (string)

Data

Word	Channel
1	Increment number
2	X position bow (yards)
3	Y position bow (yards)
4	X position stern (yards)
5	Y position stern (yards)
6	Heading (degrees)
7	Steering Rudder (degrees)
8	Flanking Rudder (degrees)
9	Starboard rpm (rpm)
10	Port rpm (rpm)
11	Rate gyro (degrees/second)
12	Wind speed (knots)
13	Wind direction (degrees)
14	X log Fwd (knots)
15	Y log Fwd (knots)
16	X log Aft (knots)
17	Y log Aft (knots)
18	Bow Range 1 (to North Causeway) (yards)
19	Bow Range 2 (to Lacombe Bayou) (yards)
20	Bow Range 3 (to South Causeway) (yards)
21	Bow Range 4 (to Lincoln Beach) (yards)
22	Stern Range 1 (to North causeway) (yards)
23	Stern Range 2 (to Lacombe Bayou) (divide by 1.7775 to obtain yards)
24	Stern Range 3 (to South Causeway) (yards)
25	Stern Range 4 (to Lincoln Beach) (yards)
26	Hours
27	Minutes
28	Seconds

TABLE 12 - DATA TAPE PARTICULARS
TAPE NUMBER 1

Run No.	File	Execute Point No.	Last Point	Run Description	Recommended Position Data
1040	1	24	118	Half Ahead Speed/RPM Calibration	Stern X,Y Track
1050	2		103	Half Ahead Speed/RPM Calibration	Bow X,Y Track
1010	3	16	91	Full Ahead Speed/RPM Calibration	Bow X,Y Track
1020	4	44	120	Full Ahead Speed/RPM Calibration	Bow X,Y Track
1070	5	4	81	Full Astern Speed/RPM Calibration	Stern X,Y Track
1080	6	14	90	Full Astern Speed/RPM Calibration	Stern X,Y Track
2000	7	10	111	Half Ahead 35R Turning Maneuver	Bow X,Y Track
2002	8	3	571	Continuation of Run 2000	(1)
2090	9	15	382	Full Ahead to Half Ahead 35L Turn	Bow X,Y Track
2100	10	3	290	Half Ahead to Full Ahead 35L Turn	Bow X,Y Track
2110	11	17	110	Full Ahead to All Stop 35R Turn	Bow X,Y Track
2115	12	15	258	Full Ahead to All Stop 35L Turn	Bow X,Y Track
2050	13	15	754	Full Ahead Steady 35L Turn	Stern X,Y Track
2130	14	15	841	Full Astern Steady 35R Turn	Bow X,Y Track
4080	15	14	225	Full Astern to Full Ahead Accel/Decel	Bow X,Y Track
2120	16	14	764	Half Astern Steady 35R Turn	Bow X,Y Track
2117	17	14	370	All Stop to Full Ahead 35L Turn	Stern X,Y Track
2020	18	14	272	Full Ahead Steady 25L Turn	Bow X,Y Track
2010	19	14	280	Full Ahead Steady 35R Turn	Bow X,Y Track
2010C	20	27	145	A checking maneuver conducted at the termination of circle 2010	Bow X,Y Track
2040	21	14	537	Full Ahead Steady 15R Turn	Bow X,Y Track
3010	22	14	391	Full Ahead 10/10 Overshoot	Bow X,Y Track
2160	23	11	422	Half Astern to Full Astern 35R Turn	Stern X,Y Track
6010	24	15	459	All Stop to Ahead Port Astern Starboard Crab	(2) Stern Ranges 1,2
4010	25	14	194	All Stop to Full Ahead Acceleration	(2) Stern Ranges 1,4
3020	26	7	432	Full Ahead 20/20 Overshoot	(2) Bow Ranges 2,3
3100	27	14	1012	Full Astern 10/10 Overshoot	(2) Bow X,Y Track
2140	28	13	362	Maximum Astern Steady 20R Turn	(2) Bow Ranges 2,4
2141	29	1	1244	Continuation of Run 2140	(1)
3040	30	15	278	Half Ahead to Full Ahead 10/10 Overshoot	Bow X,Y Track
3030	31	15	416	Full Ahead to Half Ahead 10/10 Overshoot	Bow X,Y Track
3060	32	14	395	Half Ahead to Full Ahead 20/20 Overshoot	Bow Ranges 2,3
2180	33	--	410	All Stop to Full Astern 35R Turn	(3) Stern Ranges 1,3
6060	34	21	314	Full Astern 35R to All Stop Checking Turn	Stern X,Y Track
4030	35	15	249	All Stop to Full Astern Acceleration	Bow Ranges 2,3
2150	36	15	655	Full Astern to Half Astern 35R Turn	Bow X,Y Track
4020	37	7	182	All Stop to Half Ahead Acceleration	Bow Ranges 1,2
4040	38	13	310	All Stop to Half Astern	Bow Ranges 1,[illegible]
4070	39	15	118	Half Astern to Full Ahead Accel/Decel	Bow X,Y Track

(1) Data collection interrupted due to computer malfunction.
(2) Erratic shaft RPM data.
(3) RT position and reference stations.

TABLE 12 - DATA TAPE PARTICULARS
TAPE NUMBER 1 (Continued)

Run No.	File	Execute Point No.	Last Point	Run Description	Recommended Position Data
3130	40	15	677	Half Astern to Full Astern 10/10 Overshoot	(2) Bow Ranges 1,3
3120	41	15	375	Full Astern to Half Astern 10/10 Overshoot	(2) Bow X,Y Track
3150	42	14	664	Half Astern to Full Astern 20/20 Overshoot	(2) Bow X,Y Track
3070	43	13	433	Full Ahead to Half Ahead 20/20 Overshoot	(2) Bow X,Y Track
4060	44	15	159	Full Ahead to Full Astern Deceleration	(2) Bow Ranges 1,3
6020	45	30	197	Lateral Motion Maneuver	Stern Ranges 1,3
3160	46	11	432	Full Astern to Half Astern 20/20 Overshoot	Bow X,Y Track
3161	47	1	219	Continuation of Run 3160	
4090	48	15	615	Full Ahead to All Stop Coasting	Fairing Required
6040	49	14	72	Full Astern to Full Ahead and Rudder	Bow Ranges 2,3
6050	50	9	245	Full Ahead with Turn to Full Astern and Rudder	Bow X,Y Track
4095	51	12	565	Full Astern to All Stop Coasting	Stern Ranges 1,3
L1070	52	3	96	Full Astern Speed/RPM Calibration	Bow X,Y Track
L1065	53	4	79	Half Astern Speed/RPM Calibration	Bow X,Y Track
L1010	54	1	55	Full Ahead Speed/RPM Calibration	Bow X,Y Track
L1040	55	15	90	Half Ahead Speed/RPM Calibration	Bow X,Y Track
L1050	56	10	88	Half Ahead Speed/RPM Calibration	Bow X,Y Track
L1020	57	16	102	Full Ahead Speed/RPM Calibration	Bow X,Y Track
L1066	58	29	105	Half Astern Speed/RPM Calibration	Bow X,Y Track
L2120*	59	15	242	Half Astern Steady 35L Turn	Stern X,Y Track
L2000	60	13	194	Half Ahead Steady 35R Turn	Stern Ranges 1,3
L2010	61	15	111	Full Ahead 35L Steady Turn	Bow Ranges 1,3
L3010	62	15	116	Aborted	Bow X,Y Track
L2040	63	13	153	Full Ahead 20R Steady Turn	Bow Ranges 1,2
L3100	64	15	599	Full Astern 10/10 Overshoot	Fairing Required
L2130	65	16	164	Full Astern 35L Steady Turn	Bow X,Y Track
L4060	66	8	80	Full Astern to Full Ahead Acceleration	Stern X,Y Track
L2011	67	15	120	Full Ahead 35L Steady Turn	Bow Ranges 1,3
L3011	68	15	297	Full Ahead 10/10 Overshoot	Bow X,Y Track
L4030	69	19	180	All Stop to Full Astern Deceleration	Bow Ranges 1,3
L2140	70	15	31	Full Astern 10R Steady Turn	(3) Stern Ranges 1,3
L4080	71	15	145	Full Astern to Full Ahead Acceleration	Bow X,Y Track
L2116	72	15	124	All Stop to Full Ahead 35R Turn	Stern X,Y Track
L6020	73	30	163	Twisting Turn from All Stop	Stern X,Y Track
L4010	74	29	207	All Stop to Full Ahead Acceleration	Bow X,Y Track
L4065	75	6	112	Full Ahead to Full Astern Deceleration	Bow Ranges 2,4
L4090	76	14	81	Coasting Stop from Full Ahead	Stern Ranges 1,3

(2) Erratic shaft RPM data.
(3) RT position and reference stations.

*Run L2120 is labeled Run L2000 on tape. Check last point to double check run number when analyzing from tape.

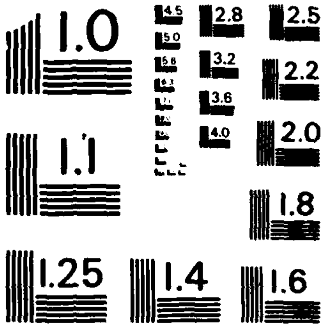
TABLE 12 - DATA TAPE PARTICULARS
TAPE NUMBER 2

Run No.	File	Execute Point No.	Last Point	Run Description	Recommended Position Data
W1040	1			Half Ahead RPM/Speed Calibration	Bow X,Y Track
W1010	2	15	91	Full Ahead RPM/Speed Calibration	Bow X,Y Track
W1050	3	12	88	Half Ahead RPM/Speed Calibration	Bow X,Y Track
W1020	4	18	95	Full Ahead RPM/Speed Calibration	Bow X,Y Track
W4060	5	15	104	Full Ahead to Full Astern Accel/Decel	Stern X,Y Track
W1065	6	15	91	Half Astern RPM/Speed Calibration	Stern X,Y Track
W1070	7	30	106	Full Astern RPM/Speed Calibration	Stern X,Y Track
W1066	8	15	91	Half Astern RPM/Speed Calibration	Bow X,Y Track
W1080	9	16	91	Full Astern RPM/Speed Calibration	Bow X,Y Track
W4080	10	--	118	Full Astern to Full Ahead Accelration	Bow X,Y Track
W6020	11	15	112	Twisting Maneuver	Bow X,Y Track
W4010	12	30	166	All Stop to Full Ahead Acceleration	Stern X,Y Track
W3010	13	15	279	Full Ahead 10/10 Overshoot	Bow X,Y Track
W2010	14	15	392	Full Ahead 35R Turn	Bow X,Y Track
W4090	15	14	835	Coasting Stop from Full Ahead	Stern X,Y Track
W4030	16	15	260	All Stop to Full Astern	Bow X,Y Track
W2130	17	15	107	Full Astern 35L Turn	Bow X,Y Track
W3100	18	15	234	Full Astern 10/10 Overshoot	Stern X,Y Track
W3101	19	15	461	Full Astern 10/10 Overshoot	Bow Ranges 1,2
W2140	20	15	222	Full Astern 20L Turn	Stern X,Y Track
W2116	21	15	142	All Stop to Full Ahead 35L Rudder	Bow Ranges 2,3
W2040	22	30	138	Full Ahead 20R Turn	Bow X,Y Track
W3021	23	8	175	Full Ahead 20/20 Overshoot	Bow X,Y Track
W2000	24	16	195	Half Ahead 35L Turn	Bow X,Y Track
W2120	25	15	221	Half Astern 35R Turn	Stern X,Y Track
W3105	26	15	584	Full Astern 10/20 Overshoot	Bow X,Y Track
R100	27	--	--	Rudder Rates	

(2) Erratic shaft RPM data.
(3) RT position and reference stations.

Tape #1 - Files 1 - 15, Monday, July 29, 1985
Tape #1 - Files 16 - 32, Tuesday, July 30, 1985
Tape #1 - Files 33 - 51, Wednesday, July 31, 1985
Tape #1 - Files 52 - 76, Thursday, August 1, 1985
Tape #2 - Files 1 - 26, Friday, August 2, 1985

AD-A169 658 MANEUVERING AND SPECIAL TRIALS RESULTS M/V BENYAURD(U) 3/3
DAVID W TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT
CENTER BETHESDA MD L L HUNDLEY ET AL. JUN 86
UNCLASSIFIED DTNSRDC-86/038 F/G 13/10 NL



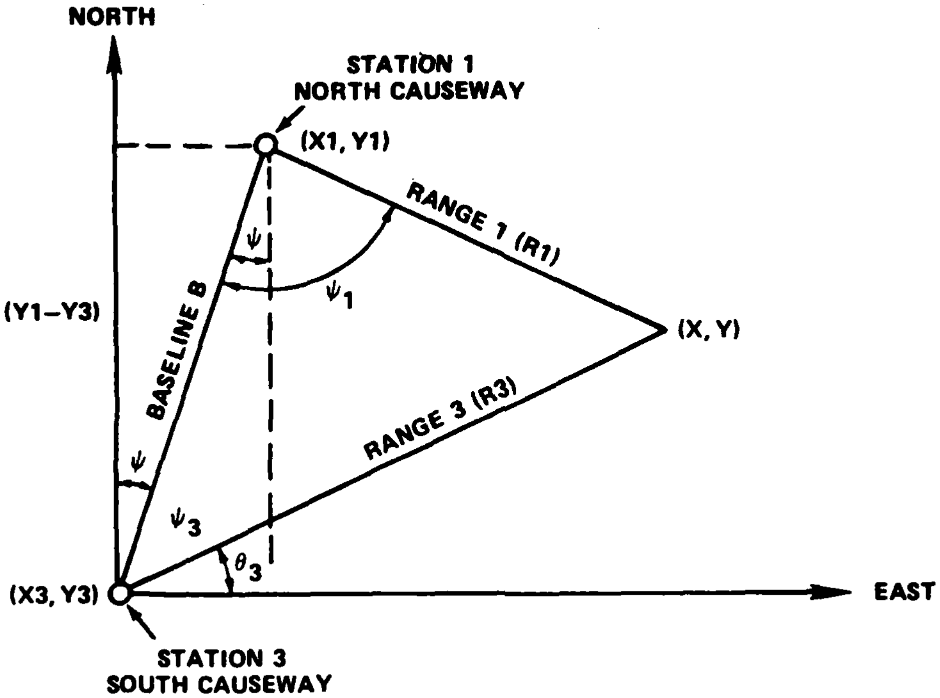
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

APPENDIX D

ALTERNATE X/Y CALCULATION

Although a significant amount of range dropout occurred during the trials, adequate and consistent position data are available for nearly all runs due to the redundant range measurements obtained. It is sometimes necessary, however, to calculate X/Y position utilizing a single baseline as opposed to the multiple baseline solution performed by the tracking console. Alternate solutions have been examined for runs which contain position shifts within the unsteady portion of a maneuver. The best alternate solution is noted in Table 12.

The best track plot for Run 2180, for example, is obtained from Range 1 and Range 3 as measured by the aft receiver/transmitter and tracking console number 1. One method of solving for the X/Y coordinates is shown in Figure 141.



$\psi = \cos^{-1}\ [(Y1 - Y3)/B]$ $\qquad$ $\psi = \cos^{-1}\ [(R1^2 + B^2 - R3^2)/(2 \times R1 \times B)]$

$\Psi_3 = \cos^{-1}\ [(R3^2 + B^2 - R1^2)/(2 \times R3\ X\ B)]$

$\Theta_3 = 90 - \Psi - \Psi 3$ $\qquad$ $\Theta_1 = 90 - \Psi_1 + \Psi$

From North Causeway:

$X = X1 = R1\ (\cos\ \Theta_1)$

$Y = Y1 - R1\ (\sin\ \Theta_1)$

From South Causeway:

$X = X3 + R3\ (\cos\ \Theta_3)$

$Y = Y3 + R3\ (\sin\ \Theta_3)$

Where $X3 = 0$ $\qquad$ $X1 = 3{,}454$ yd (3,167 m)

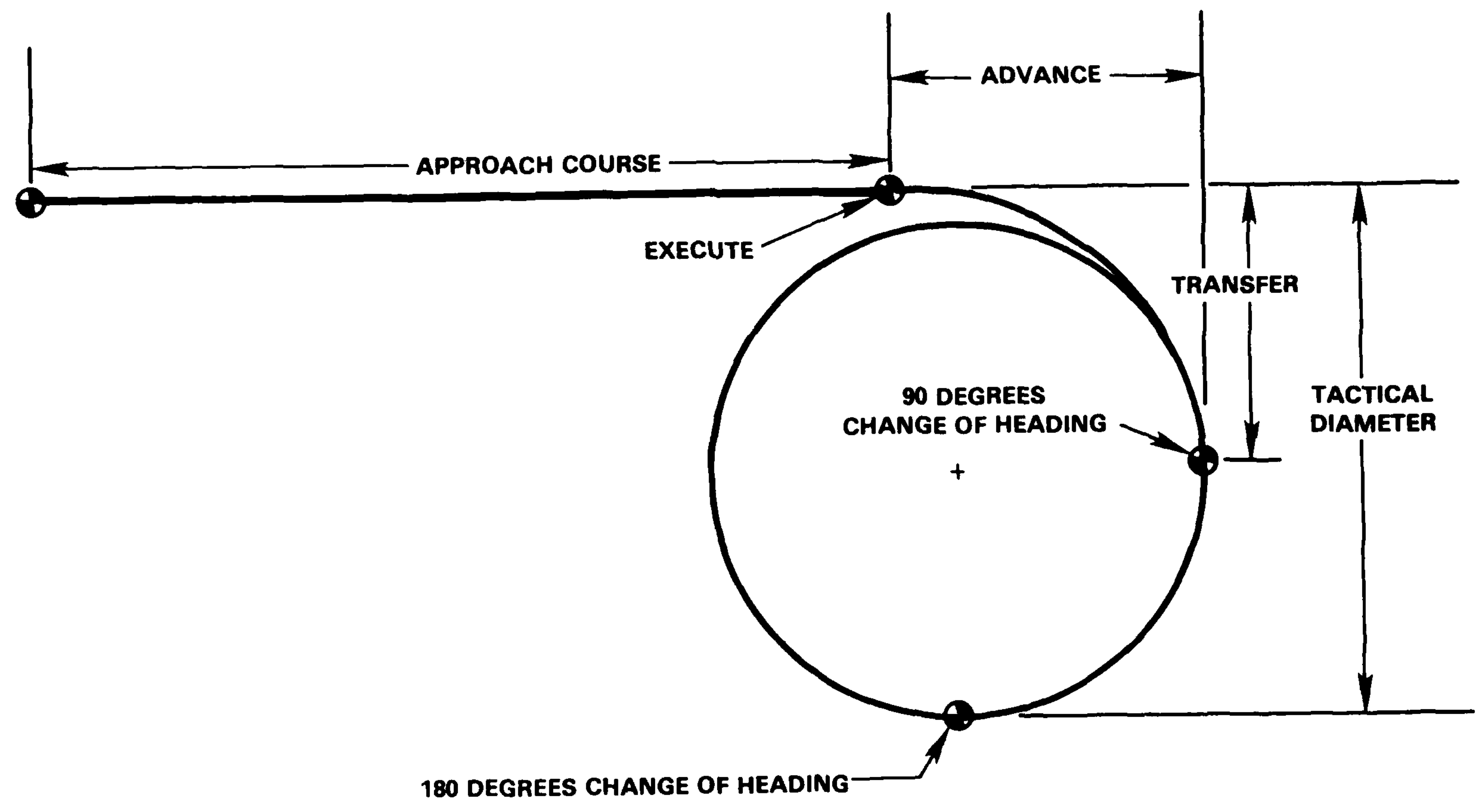
$Y3 = 0$ $\qquad$ $Y1 = 22{,}820$ yd (20,867 m)

$B = [(X1 - X3)^2 = (Y1 - Y3)^2]^{\frac{1}{2}}$

Figure 141 - X/Y Calculation from Range 1 and Range 3

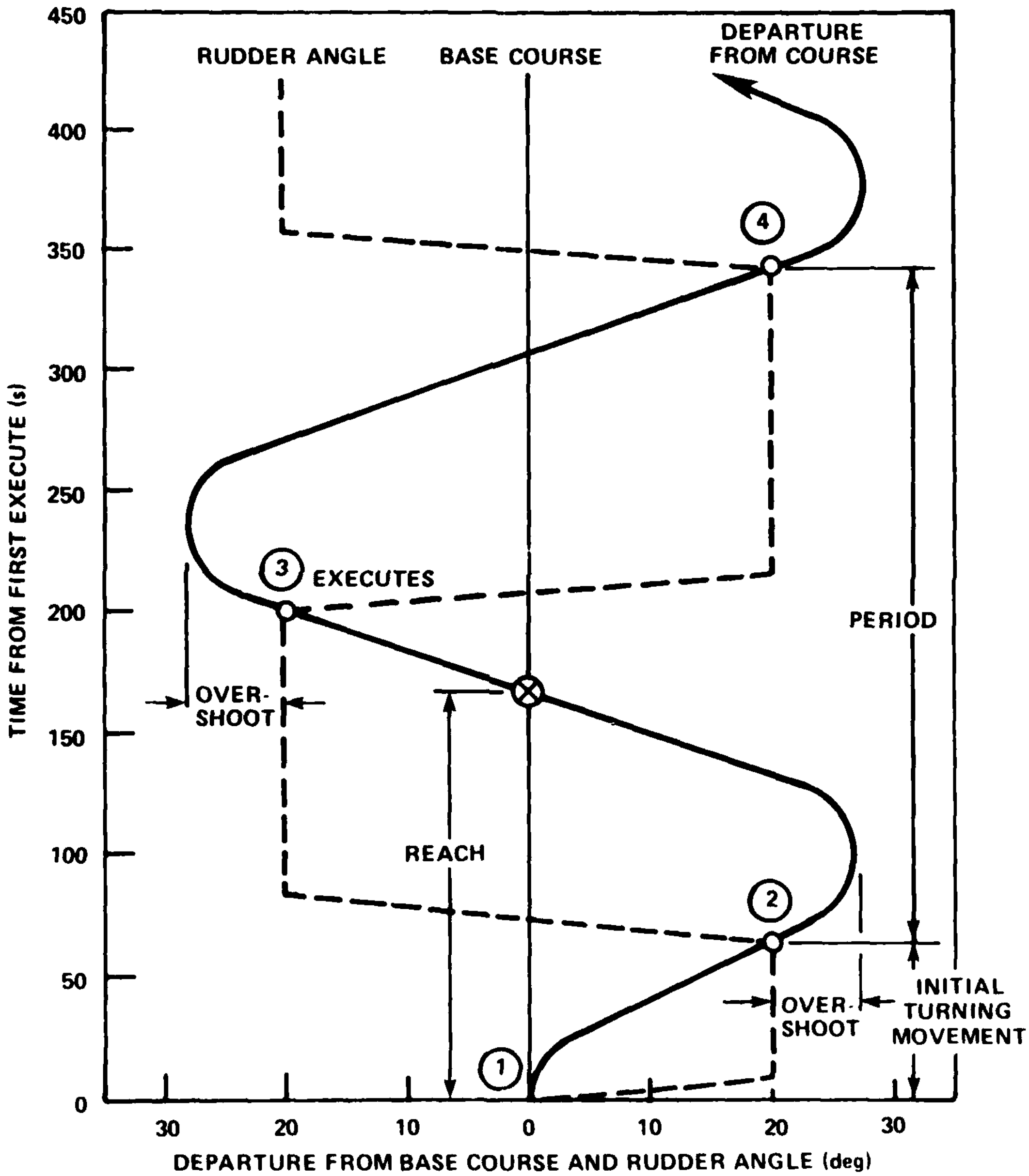
APPENDIX E

MEASUREMENTS USED TO DESCRIBE A TURNING CIRCLE MANEUVER



APPENDIX F

DETAILS OF ZIG-ZAG MANEUVER



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